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EDITORIAL

PULMONARY cavities have inspired reflection from the time of their first discovery. Even in those days it was felt that they held in no small measure many secrets of those diseases with which they were so closely and so consistently associated. They were described with care, and from a foundation of anatomical knowledge clinicians began to seek their recognition during life. We know now that the search was often fruitless or false until radiography came to help; but we can pay tribute to the diligence of those who sought, for they established the prime importance of the cavity.

So far as the tuberculous are concerned the accent has rested upon differing aspects at varying times. The importance of the cavity as a source of symptoms was the first to enter the limelight; and not long after that the influence which it exerts as a direct cause of protracted disease. Then came recognition of the cavity as the cradle of the positive sputum. The next step was to regard the cavity as the potent focus for extensions of disease into other parts of the lung. Though all may not accept at face value the figures supporting this view statistically, and others may cavil because the thesis does not always apply to individuals, there can be little doubt among those who study ultimate results that a persistent cavity almost always implies an equally persistent risk of eventual disaster. Thus the emphasis has shifted once again, this time to consider the factors which decide the patency of cavities, and how they may be overcome.

Until recently the view was held that cavities closed, if at all, by cicatrisation starting from their walls. But more than one writer mentioned that it is quite common for the physical signs of a cavity to disappear during this process. Powell and Hartley wrote in explanation: "This does not necessarily arise from the cavity becoming obliterated, but from the bronchus with which it communicates becoming narrowed or occluded

by the dense cicatricial growth in the cavity wall, in which the sheath of the bronchus partakes. Such a cavity . . . is practically or completely closed, and this is the next best thing to its being obliterated. It diminishes in size, and ceases to take any further part in the production of pulmonary symptoms." Thus it seems that the stage was already set for the presentation of subsequent ideas.

The first move came in 1933 when Coryllos stated that closure of a cavity was dependent upon the closure of its stem bronchus. There were many difficulties to acceptance of this idea: Morbid anatomy did not lend much support, for one thing, and, for another, secondary infection of tuberculous cavities of any standing was regarded then as such a usual thing that it was not easy to explain why they should behave differently from those due to other lesions, where bronchial obstruction was known to be harmful and free bronchial drainage to be essential for healing. Time has been altering such views. Coryllos followed the second point himself, and a few years ago reported that examination of the contents of tuberculous cavities, obtained during muscle-flap operations, revealed the presence of tubercle bacilli but no pyogenic organisms either on smear or culture. Inspissated cavities also are free usually from secondary invaders. There is thus no longer reason for regarding the tuberculous cavity with a closed bronchus as of necessity always a potential danger in the same sense as a lung abscess similarly placed.

On the other aspect of the problem, the frequency with which bronchial occlusion can be related to cavities which have healed, Auerbach and Green recently gave a few pertinent facts. They found the draining bronchus to have no communication with the cavity in four examples coming to necropsy and in all of which the cavity was healed. The bronchus in all four cases ended in a scar at the blind end. The common means by which this process arises are pericavitary and peribronchial fibrosis, and also invasion of the bronchial wall itself by the tuberculous process, leading to the mural caseous ulcers, hyperplastic submucous infiltrations, submucous granulomata, and fibrous scars already described by Eloesser. From this it seems that, in both directions, recent work begins to show that bronchial occlusion may be the desirable reason for success in methods aimed at closing tuberculous cavities. Healing may occur when the bronchus remains patent by a fibrous transformation of the wall; but Auerbach and Green were able to cite one example only from an experience covering eight years, so that it cannot be common.

With the bronchial component looming large, as it does from this kind of evidence, it is natural to enquire how far its operation determines success or failure in closing cavities. In a stimulating paper in this issue Price Thomas writes of his views on this topic. Admitting the difficulties of direct demonstration, he takes what facts there are, and brings some more, to support the idea that for a majority of cavities closure depends upon a natural or artificial induction of an occluded bronchus. He discusses this thesis for each form of relaxation treatment in turn, and shows that there is nothing inherently improbable in accepting it as a unitary explanation for success with each method. But he goes further than this, for he cites the rapid changes of size which some cavities undergo, and the pressures which have been found within them, as reasons for regarding a heightened intracavitary tension as a feature of the disease, and a reason also for the notorious difficulty with which cavities disappear. In other words, cavities become, so easily, tension cavities, a process which can arise only through the intervention of the bronchial factor, this time with an incomplete obstruction acting as a check valve. Thus he regards the state of affairs in the bronchus as an arbiter of events, good or ill.

This paper goes further than its predecessors in the literature in the importance which it ascribes to bronchial occlusion, either complete or partial. It is therefore destined for criticism, and we have no doubt the author intended that it should be, for that adds spice to the interest of a subject. But critics will need to note that he has already marshalled a considerable array of evidence for an attractively simple theory.

C. H.

GENERAL ARTICLES

PULMONARY CAVITIES: THEIR PERSISTENCE AND CLOSURE

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The study and behaviour of pulmonary cavities associated with tuberculosis still attracts great attention from those treating this disease. Much of our knowledge at present is hypothetical, deduced from the behaviour of these cavities under various methods of treatment, as well as from observations of the pressures within them. There can be no doubt of the value of a working hypothesis for observed phenomena in any disease, provided it is not accepted as dogma. Here an attempt will be made to explain the formation, persistence, and closure of cavities in the lung with the object of trying to rationalise methods of treatment.

Reference should be made to certain well-known physical characters of the lung which have an important bearing on the problem. These are the negative intrapleural pressure, maintaining close apposition of the visceral and parietal pleural surfaces, and the normal retractile property of the lung. The latter retracts the lung around the hilum when the negative intrapleural pressure is counteracted, as in a pneumothorax. Both forces act upon the lung, one making the lung follow every movement of the chest wall and diaphragm, the other, inherent in the lung itself, attempting to retract it to its smallest capacity, a property on which the act of quiet expiration largely depends.

During inspiration not only the alveoli but also the bronchi increase in size, and the converse happens during expiration. This can be seen through a bronchoscope as regards larger bronchi and bronchographically for the smaller bronchi and bronchioles. The widening is most probably due to the simple mechanical pull of the chest wall on the bronchial walls, and the narrowing to the elastic recoil of the lung.

Any explanation for the closure of cavities should fittingly apply to tuberculous cavities as well as to lung abscesses and abscesses in other situations. The only requisite for rapid and complete closure of a simple acute abscess in soft tissues is efficient drainage, which allows the retractile

property of the tissues to extrude the contents with subsequent healing. The analogy between the closure of an acute lung abscess and a simple acute abscess elsewhere would be relatively easy if the retractile properties of the lung alone had to be considered. It seems probable that this property plays a dominant rôle, but the negative intrapleural pressure (chest wall pull) must be taken into consideration.

A definite percentage of acute lung abscesses close spontaneously if wide and efficient bronchial drainage is provided. How, then, can we account for the elimination of the pull of the chest wall? These abscesses, in the main peripheral, are adherent to the chest wall over a limited area; their walls are soft and there is little or no surrounding infiltration. It is suggested that these cavities close primarily by virtue of the retractile capacity of the lung, and that the chest wall pull is eliminated by the production of a compensatory emphysema in the lung immediately adjacent to the cavity—that is, a local emphysema. This emphysema by filling the space originally occupied by the cavity eliminates tension on the cavity walls. If elimination of the pull of the chest wall were the prime factor in closure and the elastic retraction of the lung played no part, it is difficult to understand how the cavity would close at all. Under these circumstances one would have to postulate a positive pressure in the surrounding emphysematous area which cannot occur.

The majority of lung abscesses do not close spontaneously and the cause of their persistence is inefficient drainage, resulting in the retention of sloughs and infected material. In later stages, however, when the walls are thickened and there is much surrounding fibrosis, the cavity remains open despite the fact that sloughs are no longer present and drainage is demonstrably free; at this time the persistence of the cavity does not depend on the bronchial factor but on the direct pull of the chest wall, resulting from changes which have occurred in the lung surrounding the cavity. When an abscess has entered the subacute or chronic stage there is an extension of pneumonitis and the surrounding lung becomes adherent to the chest wall over an increasingly large area. Fibrosis also occurs, first in the cavity wall and later in the surrounding parenchyma of the lung. These two conditions combine to eliminate the retractile property in the area of lung affected, but even if this was retained they preclude any hope of a localised emphysema by which the cavitated area could be filled. The fact that the diseased area of lung has become increasingly attached to the chest wall also precludes any advantage which might accrue from the development of an emphysema beyond the diseased area, as this area, by means of its attachment to the chest wall, is made to occupy the same space as before. The fibrosis which occurs in the cavity walls and

surrounding lung may also prevent closure, despite the above consideration, as the walls themselves are rigid and undeformable.

It is more than probable that many tuberculous foci act in this same way, rupturing into a bronchus, and then acquiring free drainage so that no cavity persists. The majority of tuberculous cavities, certainly all those which are presented for surgical intervention, have no such fortunate issue. In some respects these cavities are comparable with those of persistent lung abscesses, where closure fails because of inefficient drainage.

Lung abscesses differ from tuberculous cavities in many respects. For instance, the severity of infection in a lung abscess rapidly menaces the life of the patient unless drainage is efficient. Then again, the rate of change in the surrounding lung parenchyma differs; in lung abscess fibrosis ensues relatively rapidly when drainge is inefficient, but in tuberculous lesions fibrotic changes in the walls appear late and are so rarely of the same severity that it is in fact common at post-mortem to find supple walls even in long-standing cavities. Another contrast is between the grade of bronchus into which these cavities drain; in a lung abscess it is of the third to fifth degree, whilst in a tuberculous cavity the smaller bronchi are involved.

A tuberculous cavity results directly from the rupture of a focus into a bronchus, thus effecting a breach in the lung parenchyma which communicates with the bronchial air stream. Allowing that free drainage leads to disappearance of the lesion, as occurs with an acute lung abscess, then persistence of the cavity must be the result of inefficient drainage; but if this be so then the mechanism of such persistence must be different from that which operates with a lung abscess. It cannot as a general rule be due to obstruction by retained secretions themselves, as these cavities are usually full of air with little or no retained secretion. There seem to be three possible explanations for persistence of such cavities:

1. Continued ulceration of the cavity wall.
2. Pull of the chest wall.
3. Inflationary effect of the bronchial air stream.

1. *Continued Ulceration.*—Ulceration is the original cause of the abscess, and early on is a potent factor. It is an element also later on even to the time of arrest, as is evidenced by the continued production of purulent sputum containing tubercle bacilli. In a small proportion, it is doubtless the dominant factor responsible for the persistence of a cavity, but this cannot be conceded for the large majority. Sometimes, for instance, rapidly enlarging cavities are unaccompanied by either cough or sputum, a fact which seems to limit the importance of ulceration as a prominent

cause of progressive excavation. It is also noticeable that in many rapidly growing cavities there is no radiological evidence of gross surrounding infiltration.

2. *Pull of the Chest Wall.*—This factor probably plays no part in persistence of a cavity at the early stage now under consideration, but it comes into play during the later and more advanced stages of the disease. The part played by the two forces, negative intrapleural pressure (chest wall pull) and the inherent retractibility of the lung, has been considered in discussing the closure of a lung abscess. There are, however, certain considerations which need elaboration.

In early tuberculous cavities there is usually more infiltration in the surrounding lung, and the latter is less commonly adherent to the chest wall, than in a lung abscess. The latter seems to be the more important consideration so far as cavity closure is concerned, for, once closure has begun and shrinkage in the size of the cavity has occurred, a compensatory emphysema will occur in the lung adjacent to the infiltrated area—a distance compensation, as it were. If the pleural surfaces are free, retraction can occur and the emphysematous area will enlarge to occupy the potential space thus created. In other words, in the early stage of tuberculous cavitation a compensatory mechanism is present, coming into play easily if cavity closure commences; and for the same reason advanced when considering lung abscesses the negative intrapleural pressure cannot then be considered to exert an exclusive or even cardinal influence in deciding whether a cavity persists at this early stage.

It is similarly true that, at a later stage where the whole cavitated area is attached to the chest wall, the chest wall factor is all-important in a large majority of cases. Free bronchial drainage is present in many, as shown by investigation of the intracavity pressures which are atmospheric and cannot be raised or lowered by introduction or aspiration of air.

It should be mentioned here that one of the theories of cavity persistence is the pull of the elastic fibres of the lung parenchyma which have been ruptured in the ulcerating process. It seems impossible that this can be the correct explanation, for if so it is difficult to see why any formed cavity could possibly close in the intact chest. In the example of an acute lung abscess with widely open bronchial drainage, it would be necessary for the compensatory emphysema to exert a positive pressure on the cavity walls, a supposition which can hardly be envisaged. In the majority of tuberculous cases, as will be shown later, cavity closure does not depend on a widely open bronchus. If the above thesis is accepted postulating the summation of the two intrathoracic forces (the negative intrapleural pressure and the pull of the elastic fibres) which operate to keep the cavity walls apart,

then there is no force left to effect closure. These circumstances would demand active methods of relaxation in order to close every cavity, a proposition which is manifestly wrong.

It is interesting to note in this connection that when the lung is injured by bullets or shell fragments there is no evidence of retraction of the elastic fibres to form a cavity, a sequel that might be expected if elastic retraction played a dominant part.

3. *The Inflationary Effect of the Bronchial Air Stream.*—This can be produced by:

(*a*) Increasing the endobronchial pressure by coughing or straining. This was mentioned by Woodhead (1912), but it does not play an important part in the early stages of the disease.

(*b*) Trapping of air in the cavity by some valvular effect in the bronchus.

The latter is probably the most important factor and will be considered in detail. Coryllos (1938) was the first to draw attention to the probable rôle of the draining bronchi in the solution of the problem, and although positive pressure in cavities was recognised by Pearson (1930) long before this, Coryllos, by visual means through a cavernoscope, first satisfactorily demonstrated the valvular effect of the bronchus in these cavities by observing air bubbling through secretion into the cavity after the pressure had been lowered by the aspiration of air. This thesis is supported by certain facts observed during the investigation of intracavity pressures—viz.:

1. All cavities have a demonstrable communication with the bronchial tree so that there is no such thing as a blocked air-containing cavity.

2. Cavities can be divided into two groups:

(*a*) Those in which a mean positive pressure is permanently or intermittently present.

(*b*) Those in which free bronchial drainage exists permanently, as shown by an inability to induce mean positive or negative pressures by the introduction or aspiration of air.

In this latter group persistence of the cavity is not due to the bronchial factor but to the pull of the chest wall, and personal experience suggests that these cavities cannot be closed by external drainage of the Monaldi type.

The trapping of air in the cavity has been explained by kinking or distortion of the bronchus, but it is difficult to conceive how the necessary degree of distortion could occur in early stages of the disease. Discussing tension cavities, Brun *et alii* (1941) have suggested recently that swelling of the mucosa may produce a partial bronchostenosis with the result that

during expiration the bronchus is practically occluded, thereby preventing free exit of the contained air. During inspiration, however, as a result of the inspiratory tug on the bronchial walls, the lumen of the bronchus increases in size, allowing free entrance of air. There is some pathological evidence to support this thesis, but, as can be appreciated, the opportunity of adequate proof is rarely found among those with early lesions. None the less the hypothesis of a mucosal œdema is worth retaining for it goes far to account for a valvular behaviour of the bronchi at a time when cavitation is commencing.

That there is in fact some valvular mechanism is suggested by observations on the pressures within cavities. In the majority of tension cavities the removal or introduction of air will make the pressure respectively more negative or positive than before. After a varying length of time a return to the original pressure will be observed. This suggests that there is a valvular mechanism capable of a dual rôle under certain conditions.

The possibility of a two-way by-pass has to be admitted, for the effect of an inlet valve only would necessarily be to produce a steady increase in the size of any cavitated area. Such increase does occur but in the intact chest it is not a frequent occurrence. Investigation of intracavity pressures show that there is a respiratory variation in the pressures, the most positive phase occurring during expiration, and the least, or most negative, phase during inspiration. It is suggested that when the intracavity pressure becomes greater than the endobronchial pressure during the inspiratory phase air will then flow out of and not into the cavity. In other words, there is a phase when the intracavity pressure during inspiration is the same as that in the bronchial tree, so that an equilibrium is established. The size reached by the distended cavity before this equilibrium occurs depends on the elasticity of its walls, which in turn probably depends on the degree of infiltration of the surrounding lung.

This by-pass valve effect is an intermittent phenomenon, for it is not constantly demonstrable. The cause of this intermittence is not clear, but possibly it may be due to variations in the degree of swelling of the bronchial mucosa.

To summarise: A tuberculous cavity results from the rupture of a focus into the bronchial tree. If there is a free drainage opening or openings then closure of the cavity will result provided that a compensatory emphysema can occur to take the place occupied by the cavity. Closure under these circumstances of free drainage is started by the normal retractability of the lung, and the mechanism is only prevented from operating when either compensatory emphysema or re-expansion of atelectatic lung cannot occur to fill the space. In the majority of persistent

cases where the possibility of compensatory mechanism is present, and where the chest wall factor does not operate and continued ulceration plays no more than a small part, the only factor preventing occlusion must be the bronchial factor. With this in mind it is suggested that the main cause of persistent tuberculous cavitation in early cases is the trapping of air in the breach made in the lung parenchyma; in other words, a tuberculous cavity is a tension cavity from its inception.

If the suggested hypothesis of cavity persistence is correct, solution of the main problem involved in the closure rests with elimination of the inflationary element. This can be achieved by establishing free bronchial drainage, by preventing air from entering the cavity by producing stenosis of the draining bronchus, or by establishing free communication between the cavity and the outer air by (1) the method of Monaldi (1938)—*i.e.*, tube drainage—or by (2) Eloesser's technique of turning a skin flap into the cavity.

Free bronchial drainage, though it can be regarded as effective for closing tuberculous cavities in early cases just as for lung abscess, is less effective later on, for closure is then prevented by the pull of the chest wall. Therefore it appears that Coryllos was correct in postulating that closure of the drainage opening leads to closure of a cavity because the contained air cannot then be replaced as it is absorbed. This contention has been supported recently by Auerbach (1941) in reporting 134 post-mortem examinations on patients after thoracoplasty. He found that cavity closure had occurred in 17, in all of which the bronchi draining the original cavities were closed, ending blindly in the fibrous layer of the cavity wall. All the remainder had persistent cavities and in each one patent draining bronchi were found.

The mechanism of bronchial closure, in the early stage at least, seems to be a diminution of the inspiratory tug on the bronchial walls. This, in the presence of a partial bronchostenosis occluding the bronchus in the expiratory position, will convert a partial into a complete stenosis and so prevent inspiratory entry of air into the cavity. Relaxation methods which diminish the size of the lung also reduce the calibre of the bronchi and similarly will tend to convert a partial into a complete bronchostenosis. These two factors form the fundamental basis of the majority of therapeutic measures employed in cavity closure. Eventual closure and healing of the lesion depend on the absorption of air from the cavity and the patient's ability to arrest the tuberculous process in its walls. Occasionally after bronchial closure and absorption of air the tuberculous process in the wall continues, with the result that the cavity fills with secretion producing a rounded radiological shadow. In our experience this occurs relatively

early in the disease, when it is predominantly exudative. These are truly blocked cavities, and the term " blocked," if used at all, should be reserved for this group, for there is no such thing as a blocked air-containing tuberculous cavity. This seems to be the only hypothesis which will not only account for closure of cavities but also for those anomalies where cavities persist in spite of apparently efficient relaxation or close in the presence of inefficient relaxation.

If we accept the above hypothesis of cavity persistence and cavity closure it can be understood that the same underlying principles should apply to these problems whatever the method of treatment adopted. The methods will vary depending on the state of evolution of the disease, the mechanical feasibility of their application, and last, but not least, those imponderable factors of the general state of the patient and associated risks.

Before discussing the application of these hypotheses to the various methods of treatment it is well to consider the necessity for closing cavities. Much confused thinking on this subject arises in the main from statements that a cavity, as such, is of no significance providing that it is unproductive of symptoms of toxæmia and that the patient is otherwise well. As evidence, examples from personal experience are cited of individuals who have lived for ten or twenty years with a cavity and positive sputum. The existence of such cases is common knowledge, but those who regard them as good reason for neglecting the persistent cavity can hardly realise the rarity with which so fortunate an issue is forthcoming. Further, their argument takes no cognisance of cavitated cases where, after years of good health, a recrudescence around the cavity or a contralateral extension of the disease eventually occurs. There is, however, some reason to think that the mere presence of a cavity affects the persistence of active disease. Assuming that all cavities until late in their evolution are tension cavities, it seems probable that this tension has a deleterious effect on the local defence mechanism, in so far as tension within the cavity by pressure on the surrounding walls may embarrass the blood supply on which the local mechanism of defence and repair depends. The fact that external drainage, which decreases the intracavity pressure, leads to a rapid decrease in the numbers of bacilli in the secretions and sputum points to such an effect, as also do the observations of Davidson (1941) with cavernoscopy when fresh capillaries can be seen appearing in the cavity walls after external drainage, appearances which have been personally confirmed. It thus seems that tension within a cavity may well have a direct effect on the persistence of the disease irrespective of the patient's general resistance. To return now to these patients with cavities enduring for long periods without toxic symptoms, the suggestion is made that such cavities have

ceased to be tension cavities by establishing free bronchial drainage, and that these fortunate patients have, by their own general resistance, weathered the initial storm. Doubtless a few overcome the tuberculous infection completely and are left eventually with a simple cavity lined by fibrous walls.

The rational procedure is to treat all tuberculous cavities as a potential mortal danger to the patient himself and a source of infective danger to those about him. We should condemn the thesis that the cavity as such is of no significance, if only because it is so great a temptation to use *laissez-faire* methods while hoping that the patient may reach the distant and uncertain promised land of a twenty-year survival. Only by a strict regard for the cavity shall we decrease that large army of dead who, following the other road, fall by the way. Our therapeutic aim in the treatment of this disease should be to control the spreading lesion, deal with the cavitated areas and if possible restore the patient to a normal physiological state. It is outside the scope of this discussion to consider anything other than the cavitated area, and stress must be made at the outset that the cavitated area includes not only the cavity but also that of the draining bronchi.

Bed Rest.—Every early case of pulmonary tuberculosis is rightly submitted to bed rest; with this the whole profession agrees. It is not yet universally recognised, however, that the principles underlying rest in bed are identical with those underlying other active treatments used at the present time. Excluding chemotherapy, the beneficial effect of all our treatment depends on decreasing the respiratory excursion of the diseased area of lung. The effect of this is twofold: (1) It decreases the flow of toxic lymph from the diseased area. Lymph returns to the blood-stream from all parts of the body largely as a result of movement. This decrease in toxin dose per unit of time doubtless accounts for the beneficial improvement following bed rest and artificial pneumothorax. (2) It produces relaxation, which concerns us most here. In instituting bed rest relaxation is achieved in a passive rather than an active manner, in that bed rest decreases tissue oxygen demand and results in shallower respirations with diminished excursion of the chest wall. The effect of this decrease, especially in the inspiratory phase, can be easily understood on the basis of the foregoing hypothesis. Assuming that a partial stenosis of the bronchi exists, then, if the decreased tug is insufficient to open them during inspiration, a complete occlusion results at this stage, persisting if conditions remain the same, so that the cavity will therefore close. On the other hand, if the inspiratory tug is enough to open the bronchi air will still be admitted to the cavity, so that it will persist. The important conclusion to be drawn from this assumption is that bed rest as a method of cavity closure should

be maintained for as long as there is definite radiological evidence of decrease in the size of the cavity. Bed rest should also be complete; by this absolute rest is not intended, as this is very irksome and should be enforced only on the clearest indications. It should be clearly appreciated, however, that eighteen hours in bed with six hours up is no method for producing cavity closure, as, although bronchial occlusion may occur during rest, the active exercise will re-establish a by-pass valve and inflation of the cavity will recommence.

Artificial Pneumothorax.—Artificial pneumothorax is instituted with reference to cavities, when a cavity fails to close by bed-rest procedure; other indications do not concern us here. This is undoubtedly the most efficacious method for closing cavities, giving 90-95 per cent. of satisfactory results when the pneumothorax is perfect—that is, without adhesions. In adopting this method we still depend on the decreased respiratory movement of the diseased area as well as relaxation, both being greater in extent than with bed rest. Relaxation now takes on an active character in that the natural recoil of the lung is allowed greater play. In a perfect pneumothorax when cavity closure results the mechanism of its closure can be easily understood on the basis of the present hypotheses; there are, however, certain anomalies which need consideration. Not infrequently cases are met with where a cavity is held out by adhesions in such a manner as to suggest that it is mechanically impossible for the cavity to close; this is true in one group of cases, but in others, apparently similar in all respects, the cavity unexpectedly closes. The surprise produced by such a satisfactory result is occasioned by focusing attention only on the cavity and completely ignoring the area of the draining bronchi. One explanation that can be offered is that in successful cases the drainage area is relaxed and the inspiratory tug on the draining bronchi removed, so that bronchial occlusion with cavity closure results. In the unsuccessful cases, however, the lines of inspiratory stress are across the drainage area, producing widening of the draining bronchi and admission of air into the cavity. The advantageous effect of added diaphragmatic paralysis in cases where efficient lateral relaxation is present, as in cases with vertical apical adhesions, and basal cases where the lower lobe is adherent to the diaphragm, can be similarly explained. In certain cases where a pneumothorax has been induced the cavity instead of getting smaller gets larger and balloons into the pneumothorax; this occurs not only when adhesions are present but also in cases where they are absent or have been successfully divided. Where adhesions are present the ballooning is easily understood from what has been said above. When there are no adhesions the answer does not seem as simple, yet the same principle is involved. Even in a perfect pneumo-

thorax the lung still undergoes respiratory variations in volume; in other words, it is still subject to similar respiratory stresses, though admittedly to a lesser extent. With this in mind it is suggested that even though perfect relaxation is achieved the inspiratory tug on the partially stenotic draining bronchi is still sufficient to allow air to enter the cavity. That these cavities are tension cavities can scarcely be denied, as all rapidly increasing cavities in the intact chest have invariably proved to be so. The rapidity with which they increase suggests that the absence of the support of the chest wall allows them to balloon into the pleural air space. In our experience these cases occur most commonly with bilateral disease, a feature which suggests that increased respiratory stress plays a part. When the pneumothorax is abandoned in these cases the cavity nearly always returns to its original size, but in some cases closes. The former result can be understood, as the lumen of the bronchus will increase during re-expansion so that the valvular mechanism becomes less evident; in the latter cases, maybe, an increased swelling of the mucosa as a result of the altered state of the lung leads to bronchial occlusion and closure.

The question of kinking of the bronchus should be considered here. Formerly this expression was used rather vaguely to explain the behaviour of the draining bronchi, but this use should now be discarded and the term reserved for that small though definite group of cases in which it is probable that actual kinking of the bronchus does occur. These cases are of upper lobe disease with adhesions where, after adhesion section has been performed, the lobe topples over on itself, with the result that the cavity balloons rapidly in the course of hours. Unless this state of affairs is rectified by correct posturing, the cavity ruptures into the pleura. In these cases kinking occurs in the larger branch bronchi and is a definite danger to be avoided. Kinking of a bronchus is never a beneficial event, and, contrary to what is sometimes stated, is a serious menace.

In certain cases, with a perfect pneumothorax, the cavity persists but does not balloon. This generally occurs when the lobe is atelectatic. The lack of ballooning is explained by the resistance to distension of the surrounding collapsed lung, so that pressure equilibrium in the cavity is reached before ballooning occurs. In this type of case it is sometimes noticed that a pleurisy with effusion is followed by closure of the cavity, even though the effusion is insufficient to compress the cavity or its drainage area. It is probable that the pleurisy with its attendant pleural thickening is responsible for closure as it decreases the respiratory tug on the lobe and its contained bronchi, so converting a partial into a complete stenosis. The question of positive pressure pneumothorax in connection with these cases has also been raised. It is, of course, agreed that positive pressure

pneumothorax when the lung is adherent is to be deprecated owing to the risk of tears with their complications. Positive pressure in a complete artificial pneumothorax has no such objection, provided the mediastinum is firm. The good result in this type of case can be explained by the further limitation of respiratory movement of the lobe and the drainage area.

Endobronchial Balloon.—The use of an endo-bronchial balloon, as advised by Brooks (1938), can be conveniently discussed here, as its field of usefulness is in association with an artificial pneumothorax. We have never seen any benefit from its use in cases where the lung has been fully expanded, or after thoracoplasty. In the majority of cases in which it has been used it is easy to explain the result on the basis of the present hypothesis, for in these cases the obvious result, occurring in a few hours, is an atelectasis of the lobe supplied by the occluded bronchus; this contraction of the lobe, by decreasing further the lumen of the bronchus, presumably converts a by-pass valve into a check valve—*i.e.*, bronchial occlusion. One personal case, however, cannot be so easily explained. This patient with a positive sputum and a mild pyrexia had a lower lobe cavity in a perfect pneumothorax, associated with a lobar atelectasis; a phrenic interruption had been performed and large and frequent refills had been employed, and yet the cavity still persisted twelve months afterwards. It was decided to introduce a balloon, but with little hope of success. The balloon was introduced into the lower lobe bronchus, but on removing the bronchoscope it was accidentally pulled upwards until it was opposite the upper lobe orifice, with the result that the upper lobe became atelectatic. Surprisingly the cavity closed, the pyrexia settled and the sputum disappeared. Three suggestions can be offered in this case: (1) The collapse of the upper lobe in some way, perhaps by depressing the level of the lung root, altered the lines of stress on the draining bronchi and so permitted its occlusion; (2) cutting off the bronchial air stream even for only eight hours was sufficient to allow absorption of enough air from the cavity to decrease the tension and so produce closure of the drainage opening; or (3) the endo-bronchial manipulation was such as to induce further mucosal swelling and so lead to occlusion.

Extra-Pleural Artificial Pneumothorax.—Extra-pleural artificial pneumothorax for the purpose of this discussion behaves in the same manner as the intra-pleural variety, provided the degree of extra-pleural strip on the chest wall and mediastinum has been extensive enough to relax efficiently the cavity and its drainage area. There is, however, one difference between the two—viz., that the relaxed area of lung in the extra-pleural type is not subject, in the same manner, to the respiratory excursion of the chest wall, once the stripped area has consolidated, and in consequence, theoretically

at least, ballooning of the relaxed cavity should be less likely to occur. This has not happened in our experience.

Diaphragmatic Paralysis.—Diaphragmatic paralysis, which undoubtedly does induce cavity closure in a certain percentage of cases, depends for its success on the same underlying principles. Indiscriminate and wholesale application with its many resulting disappointments arose from the fact that, as a relaxation method, it is usually a long distance procedure. It has, of course, in its favour relative simplicity of execution, small risk, and it leaves no disfigurement worthy of mention. These are valuable assets and cannot be lightly discarded. Its adoption in a definite case, however, demands careful consideration as to the likelihood of success, for when unsuccessful, especially when permanent, it carries certain disabilities, the most outstanding being the decrease in respiratory function on that side and the increased risk of spread to the lower lobe if thoracoplasty should be performed later. If paralysis of the diaphragm is to be successful in the closure of cavities, certain prerequisites are necessary: (1) The cavity should not be attached to the chest wall; (2) there should be sufficient normal lung parenchyma around the cavity and drainage area to allow efficient relaxation. This form of relaxation operates from a distance—that is, from the lower part of the chest—when, in the majority of cases, the disease is at the apex. Observation shows that the diseased area retracts more easily than normal lung if unimpeded; consequently, when the diaphragm is raised and the local conditions are such as to allow concentric relaxation of the diseased area, a satisfactory result may be expected. But if there are factors which tend to maintain lateral stress, then vertical relaxation alone, however complete, will lead to failure in a certain percentage of cases, as it will do with any other procedure. The difficulty is to determine beforehand those cases where factors are present which are likely to lead to a disappointing result. Success is to be expected where the disease is fairly recent, where the cavity is not more than 2-3 cms. in diameter, and also where there is a surrounding area of normal lung tissue. Under these conditions vertical relaxation may eliminate the inspiratory tug on the draining bronchus, leading to its occlusion and resulting in cavity closure.

External Drainage of Cavities.—External drainage of cavities, popularised by Monaldi (1938), has further stimulated the interest, fostered by Coryllos, in the relationship between the drainage opening and cavity closure. Many interesting studies have resulted from the procedure, and doubtless others will contribute to a better understanding of this difficult problem. External drainage seems to be the antithesis of Coryllos's postulate that bronchial occlusion is essential for cavity closure; but more careful examination shows

that this is not so. As previously pointed out, external drainage is one method by which the increased intra-cavity pressure can be reduced. That this will lead to decrease in the size of the cavity can be dramatically demonstrated in many cases. In the average case, however, two things become obvious: (1) External drainage will have to be persisted in for months to produce closure. (2) Bronchial communications can be demonstrated, by the injection of lipiodol, as long as the cavity remains. Brun *et alii* and others have found that aspiration of air from a tension cavity will sometimes lead to its disappearance, but in every case the cavity returns in a matter of hours. Eloesser (1934), in a study of what he termed "blocked cavities," found in each case that a bronchial communication could eventually be demonstrated. These observations support the belief that when an air-containing cavity is present there is a communication with the bronchial tree. How, then, does external drainage lead to cavity closure? I believe that the following factors are contributory: (1) Elimination of tension within the cavity; (2) increase in the blood supply to the cavity walls which depend on the foregoing; and (3) the development of an organic stenosis in the draining bronchi which is probably the most important. Bronchial communication can be demonstrated by the use of iodised oil through the draining catheter as long as a cavity is demonstrable; conversely when the collection of oil seen at the end of the catheter, representing the cavity, is no longer present, bronchial communications cannot be shown. These facts lend support to the suggestion that an organic stenosis occurs, and this probably explains the length of time required for cavity closure after external drainage.

Thoracoplasty.—Thoracoplasty achieves the closure of cavities in the same way as with other procedures, by relaxation and decreasing the inspiratory tug on the draining bronchi so that they are occluded.

Operations involving rib resection only, even when accompanied by resection of the transverse processes as well, only achieve lateral relaxation and do not exclude the vertical stresses which are present. Failure to eliminate vertical stress probably accounts for failure to close certain cavities by this type of operation. Cases treated by this means only produce cavity closure in 35 per cent. of personal cases. The adoption of mobilisation of the apex in association with thoracoplasty as advocated by Holst and Semb practically doubled the favourable results. The reason for this appears to be that this method relaxes the apex of the lung concentrically, thus eliminating both lateral and vertical stresses. The degree of vertical stress can best be appreciated while reoperating on a case which has been previously submitted to lateral thoracoplasty. When efficient concentric relaxation is obtained, not only of the cavity but also of the drainage area,

as occurs in an artificial pneumothorax, bronchial occlusion will occur and the cavity will close. Visual confirmation of this has been obtained on more than one occasion, while reoperating on cases where the cavity has failed to close; before the apex was liberated the cavity was seen to blow in and out with each respiratory phase, but after mobilisation this phenomenon ceased. Further evidence of this effect was noticed when a cavity was accidentally opened during a reoperation; after aspirating the contents, free blowing of the bronchus was heard by all around. The apex and diseased area was then widely mobilised and the blowing ceased, suggesting that the draining bronchi were closed; these operations were done with local anæsthesia so there could be no question of variations of the endobronchial pressure produced by the anæsthetic apparatus. The same phenomena were observed when a cavity was opened during a primary operation. It suggests that in these cases the vertical stress maintained a patent bronchus which closed when this stress was eliminated. If these conclusions are correct then efficient mobilisation of the cavity and its drainage area should be carried out wherever practicable and there are no contraindications to its performance.

Summary

1. Pulmonary cavities close primarily as a result of the inherent concentric retractility of the lung, the negative intrapleural pressure (chest wall pull) being eliminated by the occurrence of compensatory emphysema in the lung adjacent to the diseased area.

2. Lung abscess cavities close as a result of the above only in the presence of free drainage.

3. Lung abscesses and tuberculous cavities persist as a result of inefficient drainage; the former by the retention of sloughs and infected material, the latter by the trapping of air in the cavity resulting from a partial bronchostenosis chiefly operative during expiration.

4. The majority of tuberculous cavities are tension cavities from their inception and remain so until the later stage of the disease.

5. During the later stage of the disease tuberculous cavities persist because of the pull of the chest wall, for at this stage free bronchial drainage is usually present.

6. Bronchial occlusion is essential for inducing closure of tuberculous cavities.

7. All methods of treatment, excluding chemotherapy, from bed rest to thoracoplasty, are based on the same basic principles—viz., limitation of the inspiratory tug on and relaxation of the cavity and its draining bronchi with the ultimate production of an organic bronchostenosis.

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THE ANATOMY OF THE BRONCHIAL TREE

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THE form of the bronchial tree and the distribution of its branches were neglected in descriptions by the older anatomists, because in those days they had little practical importance. But modern methods of investigation, such as bronchoscopy and bronchography, require a knowledge of the normal bronchial anatomy for their interpretation. In this paper it is proposed to give a short account of the comparative anatomy and embryology of the bronchial system, followed by an illustrated description of the normal human bronchial tree, based upon published researches and personal anatomical and bronchographic studies.

Embryology and Comparative Anatomy

In mammals the lungs arise as a diverticulum from the ventral aspect of the pharynx. This pouch divides into two sacs, which are pushed ventrally towards the body cavity. Each sac consists of an enlarged terminal vesicle joined to the tracheal portion by a tube, the primary or stem bronchus. Each terminal vesicle, dividing repeatedly, forms a number of smaller vesicles connected with the primary bronchus by smaller tubes, the secondary bronchi. This process is continued, forming the further subdivisions of the bronchi, while the vesicles and terminal ducts become lined with tiny diverticula, the alveoli. At a very early stage mammalian lungs become asymmetrical as an eparterial bronchus appears on the right side (Fig. 1).

The most primitive creatures with true lungs are the dipnoi or lung

fishes. Normally these oxygenate their blood in gills; the pulmonary arteries, arising from the last efferent branchial arch, carry venous blood for oxygenation in the lungs only when the gills are unable to function. Primitive lungs consist of a trachea and two bronchi, each with a simple pulmonary sac as seen in the dipnoi, the amphibia such as the frog, and in the early development of the human lung (Fig. 2, A). In higher forms the thorax becomes larger and buds growing out from the primitive pulmonary stem occupy the increased space. These buds are arranged in a regular series on the dorsal and ventral aspects of the stem; each develops a bronchus connecting with the central stem bronchus which has appeared at the same time. This type of lung is seen in the tortoise (Fig. 2, C). The stem bronchus also gives rise to smaller and less regular branches, forming accessory bronchi such as the cardiac bronchus in the mammalian right lung.

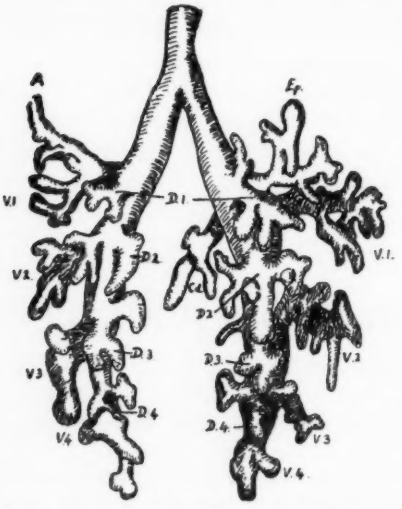

FIG. 1.—LUNG FROM 10 MM. EMBRYO OF *Didelphis marsupialis* (OPOSSUM), DORSAL VIEW, ×150. (AFTER HUNTINGTON.)

Ep, eparterial bronchus; A, ascending branch of first left ventral hyparterial bronchus; V.1-V.4, ventral hyparterial bronchi; *Cd*, cardiac bronchus; D.1-D.4, dorsal bronchi.

The dominant reptilian lung is entirely hyparterial—that is to say, in both lungs the first bronchi arise from the stem below the point at which it is crossed by the pulmonary artery (Fig. 3, I). Various theories have been advanced to account for the development of the eparterial bronchial system on the right side in mammalia, but these are outside the scope of this article. Huntington (1920) has given the most comprehensive account of the evolution of the mammalian lung. He suggested that the increased oxygenation of the blood which became necessary in passing from

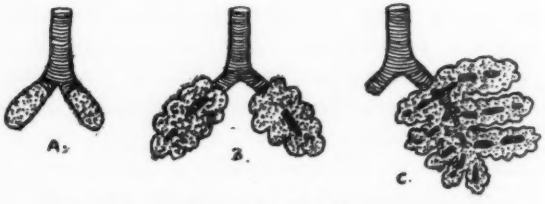

FIG. 2.—DEVELOPMENT OF THE VERTEBRATE LUNG. (AFTER HUNTINGTON.)

the poikilothermic amphibian and reptile to the homothermic mammal demanded an increased respiratory area which was provided by an expansion of the cranio-ventral portion of the lung Therefore, this portion is most highly developed in the ungulata, which have a constant high rate of tissue combustion, and in aquatic adaptations, such as the whale, with a rapid intermittent metabolism due to periods of suspended respiration. This new upper respiratory area is supplied by an ascending branch of the first ventral hyparterial bronchus (Fig. 3, I), which enlarges until it becomes as big as the parent bronchus; a cleft then appears which divides the lung into two lobes, upper and lower (Fig. 3, II). The origins

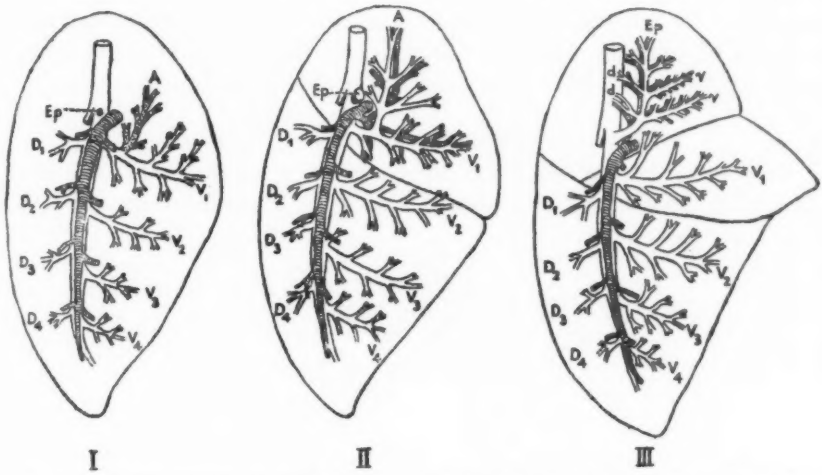

FIG. 3.—DEVELOPMENT OF THE VERTEBRATE RIGHT LUNG. (AFTER HUNTINGTON.)
Ep, eparterial bronchus; A, ascending branch of first ventral hyparterial bronchus; V.1-V.4, ventral hyparterial bronchi; D.1-D.4, dorsal bronchi; *d* and *v*, dorsal and ventral branches of the eparterial stem.

of the first ventral hyparterial bronchus from the stem and of its ascending branch are so close together that little unfolding of their upper lobe ramifications is possible; and so, in the right lung, a new bud forms (Fig. 3, Ep) in a position more favourable for supplying the upper lobe, and develops into the eparterial bronchus. It arises above the pulmonary artery from the dorso-lateral aspect of the main bronchus, and a new fissure then develops dividing the original upper lobe into two parts, the right upper and middle lobes (Fig. 3, III). The eparterial bronchus behaves as a stem bronchus to the newly developed cranial pulmonary district; it develops dorsal and ventral branches and its terminal portion

supplies the apex. In the left lung there is no eparterial bronchus, and the ascending branch of the first ventral hyparterial bronchus develops more fully to supply an area similar to that served by the eparterial bronchus on the right, but smaller. The remainder of the left first ventral hyparterial bronchus supplies an area equivalent to the right middle lobe, but in many forms, including man, there is no fissure between the upper and middle areas of the left lung. Ninety per cent. of living mammals attain this stage of development; some go a stage further, for in the ungulates and whales the eparterial bronchus arises from the trachea, while the camel and the giraffe have two eparterial bronchi in each lung. Ninety-five per cent. of mammals have an eparterial bronchus only in the right lung. The reasons for this asymmetry are far from clear, but it is probable that two factors at any rate play some part—namely, the smaller size of the left lung and the position of the left pulmonary artery (Huntington, 1920).

The Normal Human Bronchial Tree

Historical Survey.—In 1882 Aeby made the first attempt to describe the human bronchial tree in detail (Fig. 4). He regarded the primary

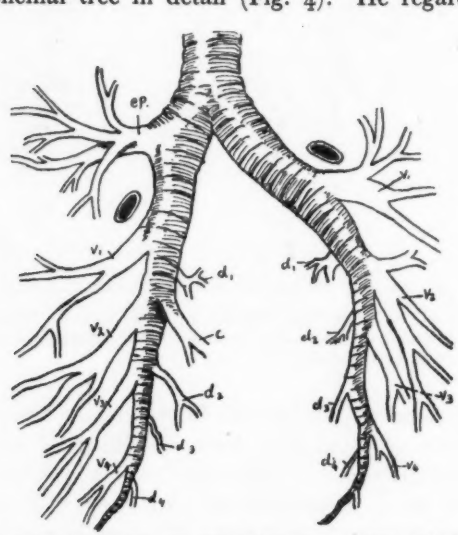

Fig. 4.—Aeby's Diagram of the Bronchial Tree (1882).
ep, eparterial bronchus, showing ventral and dorsal divisions; *c*, cardiac bronchus; d_1-d_4, hyparterial dorsal branches; v_1-v_4, hyparterial ventral branches.

bronchus in each lung as a continuous stem extending down to the base and giving rise to the following branches by monopodial division: An eparterial bronchus having ventral and dorsal branches and occurring

only in the right lung; eight hyparterial bronchi, of which four were ventral and four dorsal; accessory bronchi, only one of which, the cardiac bronchus in the right lung, was of any considerable size. Ewart, in 1889, published a very full description of the human bronchial tree based on the study of metallic casts and dissections (Fig. 5). In contrast to Aeby, he considered the branching of the main bronchus as dichotomous; but embryology suggests that Aeby's view is more probably correct, and it has been adopted by most subsequent authors. In 1929 Davis attempted to study the bronchial tree by means of radiographs taken after removal of the lungs

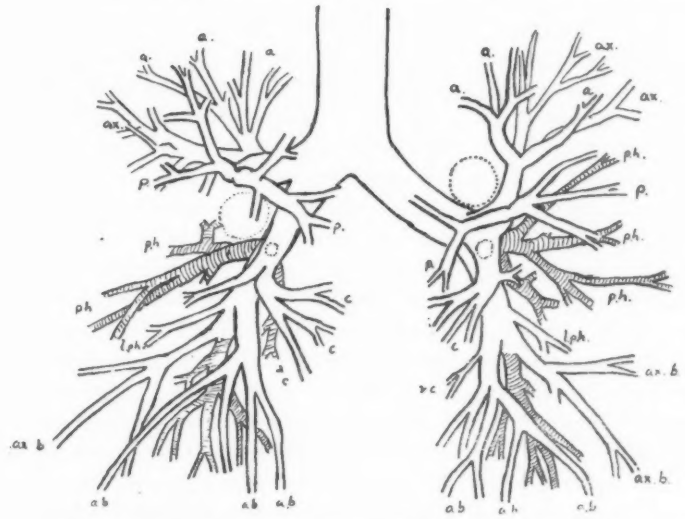

FIG. 5.—EWART'S DIAGRAM OF THE BRONCHIAL TREE (1889).

a, apical; *ax*, axillary; *p*, pectoral; *ph*, posterior horizontal (dorsal); *rc*, retro-cardiac; *lph*, lesser posterior horizontal; *ab*, anterior basic; *ax.b*, axillary basic. The posterior basic branches are seen behind the anterior basic.

from the body, and after filling the bronchi with radio-opaque material. He concluded that the arrangement was so varied that it was impossible to describe a typical distribution; but his method was unsound because frontal views alone were studied, and the bronchi were distorted by collapse of the lungs.

Nelson, in 1932, pointed out that the apical portion of the lower lobe could be regarded as a separate entity with independent bronchial and blood supply, and often demarcated by a fissure; he called this segment the "dorsal lobe." In the same year Kramer and Glass (1932) introduced the conception of the "broncho-pulmonary segment," defined as the area

of lung tissue supplied by a given bronchus. This is an arbitrary conception, and the size of any segment depends upon the size of the bronchus which supplies it; thus a whole lobe may be regarded as a broncho-pulmonary segment supplied by a lobar bronchus, while, at the other extreme, a terminal lobule may be looked upon as a broncho-pulmonary segment supplied by a terminal bronchiole. Kramer and Glass defined their broncho-pulmonary segment as an area of lung supplied by a constantly placed bronchus whose orifice was situated in a large lobar bronchus and was clearly visible to the bronchoscopist; they mapped out these areas on the surface of the lung (Fig. 6, I.). This paper and another by Glass (1934) on the same subject were of great value in showing how bronchoscopy could assist in the accurate localisation of a pathological process in the lung. Nelson, in 1934, published a short account of the distribution of the bronchi based upon the study of bronchograms. He found that Ewart's description of the principal bronchi was substantially correct, and he adopted many of the names which Ewart had applied to them. Lucien and Weber (1936) stated that the bronchi were arranged in a dorsal and a ventral series which served the corresponding areas of the lung and which gave lateral and medial branches to supply the external and internal surfaces. Thus they divided the lung into four " territories of ventilation," dorsal, ventral, internal and external, and claimed that these were constant, whereas the exact arrangement of the bronchi supplying them was not always constant (Fig. 6, IV.). Levitin and Brunn (1936) published a description of the lower lobe bronchi similar to those of previous authors. The following year, Neil, Gilmour and Gwynne (1937) gave an account of the anatomy of the bronchial tree in which they stressed the importance of a second dorsal branch of the lower lobe bronchus which they believed to be constant (Fig. 6, III.). Hovelacque, Monod and Evrard (1937) published a short description of the anatomy of the bronchi based on that of Lucien and Weber. Churchill and Belsey (1939) recently described the anatomy of the left upper lobe and of the apical portion of the lower lobe, with special reference to the surgery of these areas. Pierce and Stocking (1939) recorded a bronchographic survey of the bronchial distribution, and noted that the eparterial bronchus commonly had three branches.

Methods and Nomenclature.—The anatomy of the bronchial tree may be investigated by dissection, by making corrosion casts, by the injection of dyes or air into the bronchi to ascertain their distribution, and by the study of bronchograms. All these methods have been used here and they are described in the Appendix.

In naming the bronchi, those names which are in common use have been retained unless they are misleading (Table I.). The present nomen-

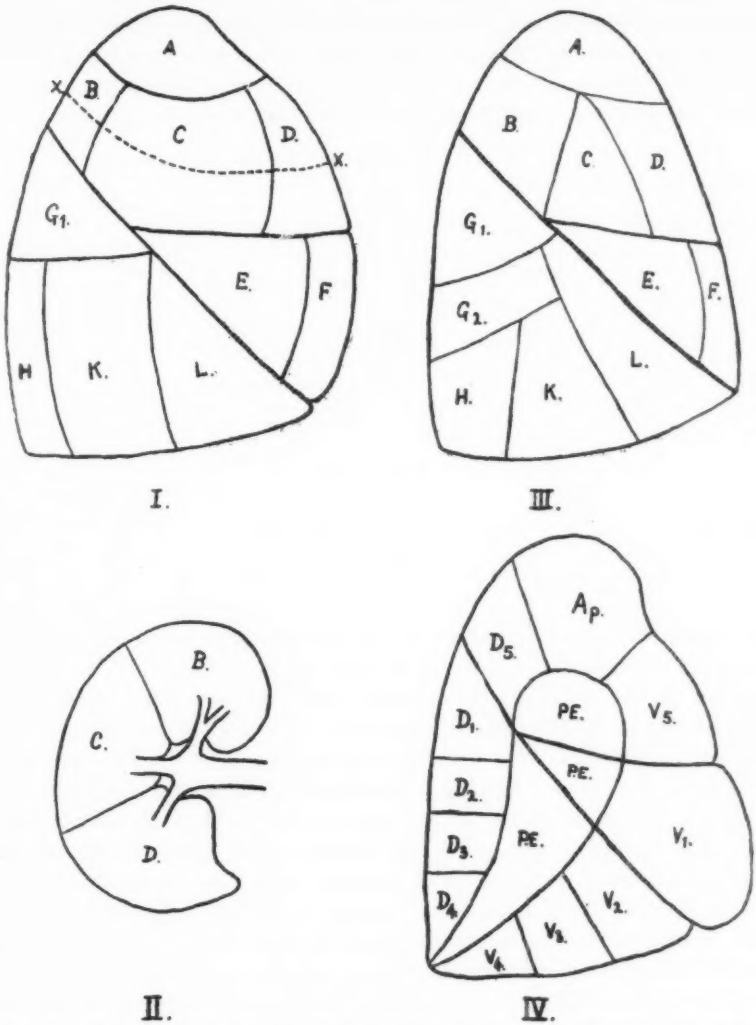

FIG. 6.—THE BRONCHO-PULMONARY SEGMENTS ACCORDING TO VARIOUS AUTHORS.

I. GLASS (1934): LATERAL SURFACE OF RIGHT LUNG.

II. HORIZONTAL SECTION ALONG LINE X-X.

III. NEIL, GILMOUR AND GWYNNE (1937): LATERAL SURFACE OF RIGHT LUNG.

Segments: Upper lobe: A, apical; B, posterior; C, axillary; D, anterior. Middle lobe: E, lateral; F, anterior. Lower lobe: G_1, apical; G_2, sub-apical; H, paravertebral; K, posterolateral; L, anterolateral.

IV. LUCIEN AND WEBER (1936): LATERAL SURFACE OF RIGHT LUNG.

Ap, apical; D_5, upper dorsal; V_5, upper ventral; PE, external parabronchial area; V_1-V_4, lower ventral segments; D_1-D_4, lower dorsal segments.

clature differs from others by the omission of the word "lobe" from the names of the bronchi. This has been done because the two lungs do not contain the same number of lobes and therefore the lobar bronchi are not comparable in their distribution on the two sides. The bronchus to the

TABLE I.—NOMENCLATURE OF THE BRONCHIAL TREE.

	RIGHT.	LEFT.	
Upper lobe.	— *Eparterial bronchus :* 1. Anterolateral. — 2. Apical. 3. Posterolateral.	*Hyparterial bronchus :* 1. *Ascending bronchus:* (*a*) Anterolateral. (*b*) Apicoposterior. I. Apical. II. Posterolateral. —	Upper lobe.
Middle lobe.	*Descending bronchus.* *Middle bronchus :* 1. Anterior. 2. Lateral.	2. *Middle bronchus:* (*a*) Anterior. (*b*) Lateral.	
Lower lobe.	*Lower bronchus :* 1. Dorsal. 2. Cardiac. 3. Anterior basic. 4. Middle basic. 5. Posterior basic.	*Lower bronchus :* 1. Dorsal. — 2. Anterior basic. 3. Middle basic. 4. Posterior basic.	Lower lobe.

right upper lobe has been called the *eparterial bronchus* because this name is universally adopted by embryologists and serves to distinguish it from the bronchus to the left upper lobe, which has a different distribution. The latter has been called *hyparterial* because it represents the first ventral hyparterial bronchus of the primitive left bronchial stem. That portion of the right stem bronchus which lies between the origins of the bronchi to the upper and middle lobes has no counterpart in the left lung, and has been termed the *descending bronchus*. The branch to the right middle lobe has been called simply the *right middle bronchus*, and a similar designation can then be applied to the equivalent branch in the left lung. The bronchus to the lower lobe has been named the *lower bronchus*; it represents the terminal portion of the primitive bronchial stem, whereas the other lobar bronchi are branches of this stem. It is for this reason that the terms primary, secondary, tertiary, etc., are misleading when applied to the bronchi. Since the bronchus to the lower lobe is part of the primary stem, its main branches are secondary bronchi, while similar branches in the other lobes have to be called tertiary, because the other lobar bronchi are themselves secondary.

Only the larger and most constant subdivisions of the bronchial tree are described in this paper; at times there are other branches of lesser importance, but these have been omitted for the sake of clarity.

ANATOMICAL DESCRIPTION—(A) *The Right Upper and Middle Lobes.*—**The eparterial bronchus** (right upper lobe bronchus) arises from the lateral surface of the right main bronchus about 1·5 to 2 cm. below the main carina. It is directed horizontally outwards and is about 1 cm. in length.

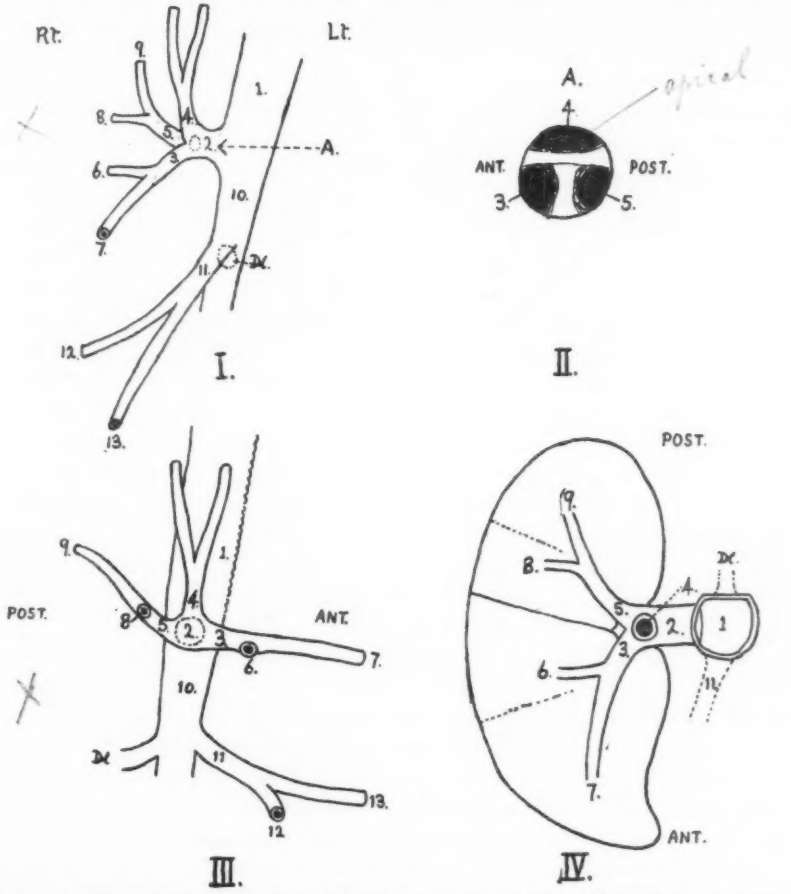

FIG. 7.—I. THE RIGHT EPARTERIAL, DESCENDING AND MIDDLE BRONCHI AND THEIR BRANCHES, ANTERO-POSTERIOR VIEW.

II. VIEW INTO THE ORIFICE OF THE EPARTERIAL BRONCHUS IN THE DIRECTION OF THE ARROW (A) IN I.

III. LATERAL VIEW.

IV. HORIZONTAL SECTION THROUGH THE RIGHT UPPER LOBE JUST ABOVE THE EPARTERIAL BRONCHUS, VIEWED FROM ABOVE.

1, main bronchus; 2, eparterial bronchus; 3, anterolateral branch; 4, apical branch; 5, posterolateral branch; 6, lateral branch of 3; 7, anterior branch of 3; 8, lateral branch of 5; 9, posterior branch of 5; 10, descending bronchus; 11, middle bronchus; 12, lateral branch of 11; 13, anterior branch of 11; *Dl*, dorsal branch of lower bronchus.

The mode of branching of the eparterial bronchus is not absolutely fixed, but the arrangement shown in Fig. 7 is by far the most common and was seen in 66 out of a series of 100 right bronchograms. It will be seen that there are three main divisions—anterolateral, posterolateral and apical.

1. Anterolateral (pectoral, anterior, upper ventral): This branch is directed forwards, outwards and slightly downwards to supply the anterior

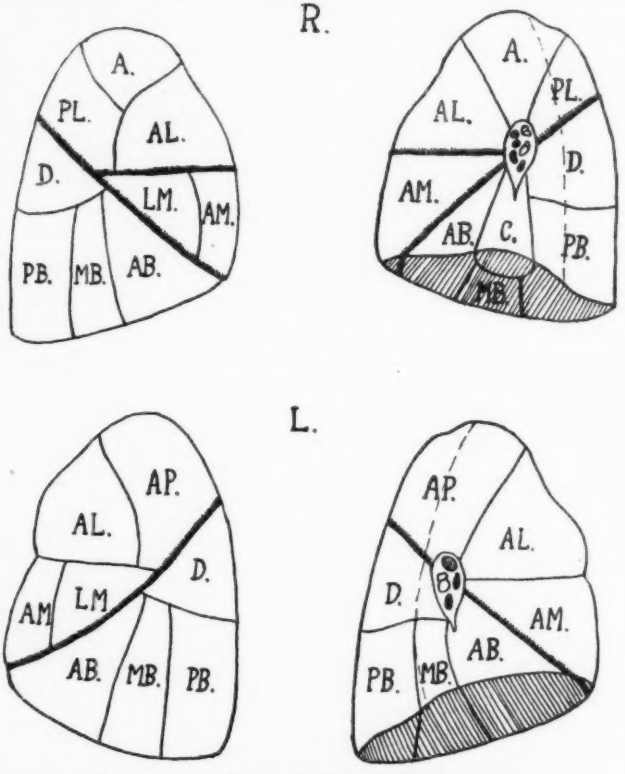

FIG. 8.—THE BRONCHO-PULMONARY SEGMENTS.

A, apical; PL, posterolateral; AL, anterolateral; LM, lateral middle; AM, anterior middle; D, dorsal; C, cardiac; AB, anterior basic; MB, middle basic; PB, posterior basic; AP, apicoposterior.

part of the upper lobe below the apex. It has a well-marked lateral division which supplies the anterior part of the axillary surface of the upper lobe, extending backwards about 1 cm. behind the mid-axillary line. The pulmonary segment supplied by this whole branch is related anteriorly and laterally to the chest wall, medially to the anterior superior mediastinal structures and below to the lesser fissure (Fig. 8 and Plate I, I.).

2. Posterolateral (upper paravertebral, upper dorsal): This branch is directed backwards, outwards and slightly upwards to supply the posterior part of the upper lobe below the apex. It also has a lateral division, supplying the posterior part of the axillary surface of the upper lobe. The posterolateral segment is related behind and laterally to the chest wall, medially to the bodies of the vertebræ and to the posterior superior mediastinal structures, and below to the posterior part of the greater fissure (Fig. 8 and Plate I, II.).

3. Apical (upper apical): The remaining branch is directed upwards and bifurcates before supplying the apex of the lung above the first rib. This segment is related to the dome of the pleura and medially to the structures in the middle part of the superior mediastinum.

The variations which have been observed in the mode of branching of the eparterial bronchus are shown diagrammatically in Fig. 9. These diagrams are drawn from the medial aspect in order to show the orifices of the branches which are visible to the surgeon when he looks into the eparterial bronchus with a right-angled bronchoscopic telescope. Many authors have stated that the axillary part of the right upper lobe is supplied by a separate branch of the eparterial bronchus (Ewart, 1889; Kramer and Glass, 1932; Nelson, 1934; Neil, Gilmour and Gwynne, 1937); they described an axillary broncho-pulmonary segment and showed this branch in imaginary sections through the right upper lobe (Fig. 6, II.). Hovelacque, Monod and Evrard (1937) agree with Lucien and Weber (1936) that the bronchial supply of this axillary area is not constant. The present investigation has shown that in 9 per cent. of individuals the lateral division of the anterolateral bronchus (Fig. 7, 6) arises so close to the eparterial trunk that it might easily have been mistaken for a separate axillary branch (Fig. 9, variation V). Plate II shows an actual section through the right upper lobe in such a case, and it will be observed that the branch to the axilla (6), although almost in line with the eparterial bronchus, arises from a very short anterolateral branch (3). In a further 4 per cent. the lateral division of the posterolateral branch has a similar early origin (Fig. 9, variation VI). In the remaining 87 per cent. of individuals no independent branch to the axilla is visible on looking into the eparterial bronchus. Thus there is no true axillary segment of the right upper lobe, this area being supplied chiefly by the anterolateral branch of the eparterial bronchus and to a lesser extent by the posterolateral branch, through their lateral divisions. The arrangement shown in Fig. 7 occurs in 66 per cent. of individuals and may be regarded as normal. Plate III shows a section through the right upper lobe in such a case. Such a structure agrees well with our knowledge of the development and comparative anatomy of the

eparterial bronchus (see p. 21), with its dorsal (posterolateral) and ventral (anterolateral) branches, similar to those of the stem bronchus.

The apical branch sometimes arises in common with the anterolateral or posterolateral, and occasionally in two parts, one from each of these branches (Fig. 9, variations II, III and IV). Very rarely the apical branch may have a separate origin higher up the main bronchus, and the whole apical segment may be separated from the rest of the upper lobe by a fissure forming a supernumerary apical lobe, which should not be confused with the lobe of the azygos vein (Stibbe, 1919). The frequency of all these

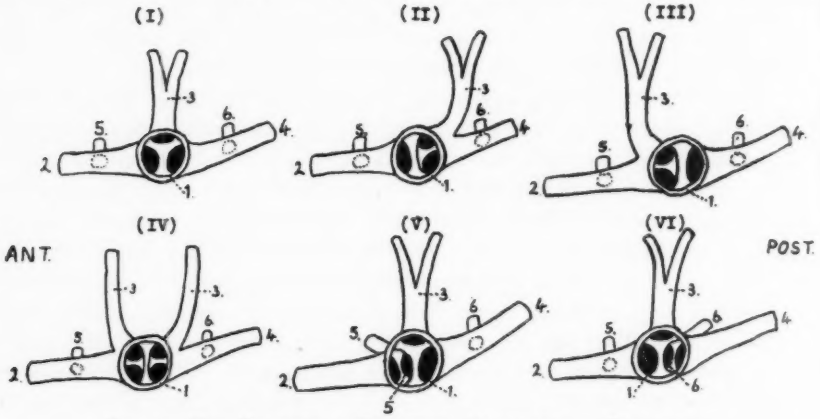

FIG. 9.—THE EPARTERIAL BRONCHUS: VARIATIONS IN BRANCHING.
1, eparterial bronchus; 2, anterolateral branch; 3, apical branch; 4, posterolateral branch; 5, lateral branch of 2; 6, lateral branch of 4. All viewed from medial aspect.

variations in the mode of branching of the eparterial bronchus is given in Table II.; they have been discussed in detail because of their importance for localising pathological processes in the right upper lobe.

TABLE II.—VARIATIONS IN THE MODE OF BRANCHING OF THE EPARTERIAL AND HYPARTERIAL BRONCHI. (SEE FIGS. 9 AND 11.)

	EPARTERIAL BRONCHUS, VARIATIONS.						
	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*Total.*
Bronchographs	66	11	4	6	9	4	100
Dissections	15	4	1	—	1	—	21

	HYPARTERIAL BRONCHUS, VARIATIONS.				
	I.	*II.*	*III.*	*IV.*	*Total.*
Bronchographs	86	4	8	2	100
Dissections	7	—	1	—	8

In the normal postero-anterior bronchogram, the branches of the eparterial bronchus are seen spreading fanwise from the parent trunk; those of the anterolateral division appear lowest and those of the apical division highest, while the posterolateral branches are seen midway between these two (Plate IV). In the normal right lateral bronchogram, the eparterial bronchus is seen in cross section as a well-defined ring, and it would seem that this shadow has sometimes been mistaken in the past for the cross section of an axillary branch. The lateral divisions of the anterolateral and posterolateral branches can usually be identified in the lateral film (Plate IV).

The right middle bronchus (right middle lobe bronchus, cardiac bronchus) arises from the anterior or anterolateral aspect of the descending bronchus about 1·5 to 2 cm. below the origin of the eparterial bronchus (Fig. 7). It is directed forwards, downwards and slightly outwards, and divides into two branches, anterior and lateral.

1. Anterior (sterno-cardiac): This branch continues the direction of the parent bronchus and supplies the anterior and inner parts of the middle lobe, extending backwards on the lateral surface as far as the anterior axillary line. This segment is related in front and laterally to the chest wall, medially to the pericardium, above to the lesser fissure and below to the greater fissure (Fig. 8).

2. Lateral (superficial mammary cardiac, axillary): This branch is directed outwards and slightly forwards to supply the lateral and posterior parts of the middle lobe. The lateral segment is bounded behind by the narrow posterior border of the middle lobe, above and below it are the lesser and greater fissures, laterally it is in contact with the chest wall, and its remaining surface abuts on the anterior middle segment.

(B) *The Left Upper Lobe.*—The hyparterial bronchus (left upper lobe bronchus, bronchus impar) is a wide trunk, about 1 cm. in length, arising from the anterolateral aspect of the left main bronchus 5 to 6 cm. from the main carina and directed outwards, forwards and slightly downwards (Fig. 10). It ends by bifurcating to form the *ascending bronchus*, which is equivalent to the eparterial bronchus in the right lung, and the *left middle bronchus*, which is the homologue of the right middle bronchus.

1. **The ascending bronchus** (left upper bronchus) represents the important ascending branch of the first left ventral hyparterial bronchus whose comparative anatomy has already been discussed; this is the reason for choosing the name " ascending bronchus." It is a short trunk directed upwards and slightly outwards and dividing into two branches, anterolateral and apicoposterior.

(*a*) Anterolateral (pectoral, upper anterior, upper ventral): This

branch, usually larger than that on the right side, is directed forwards and has a well-marked lateral division. It supplies a segment similar to the

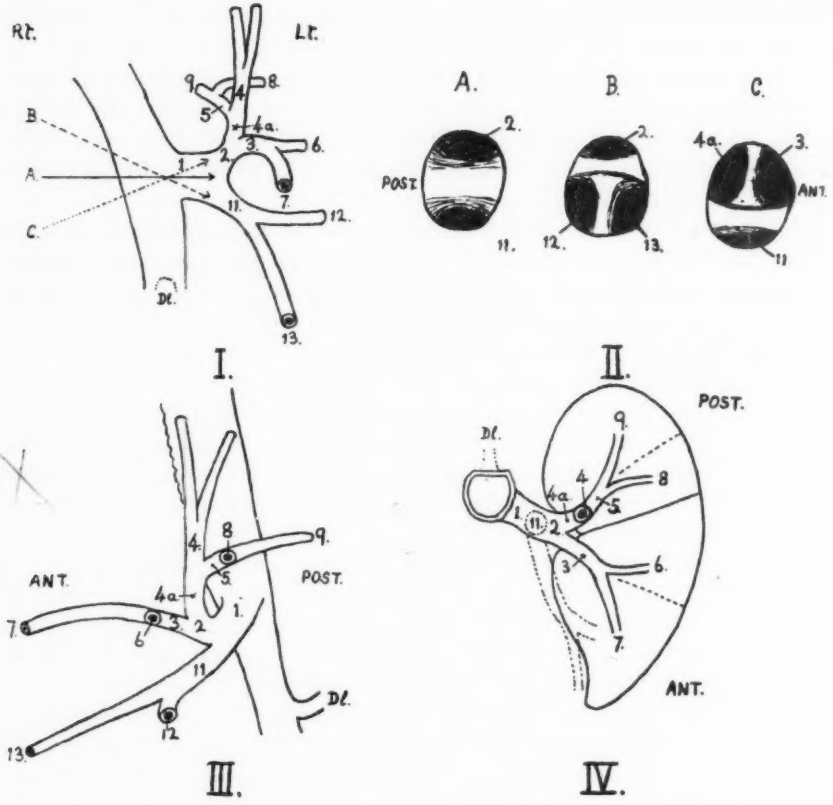

FIG. 10.—I. THE LEFT HYPARTERIAL BRONCHUS AND ITS BRANCHES, ANTERO-POSTERIOR VIEW.

II. VIEWS INTO THE ORIFICE OF THE HYPARTERIAL BRONCHUS IN THE DIRECTIONS SHOWN BY THE ARROWS IN I.

III. LATERAL VIEW.

IV. HORIZONTAL SECTION THROUGH THE LEFT UPPER LOBE JUST ABOVE THE HYPARTERIAL BRONCHUS, VIEWED FROM ABOVE.

1, hyparterial bronchus; 2, ascending bronchus; 3, anterolateral division; *4a*, apicoposterior division; 4, apical branch; 5, posterolateral branch; 6, lateral branch of 3; 7, anterior branch of 3; 8, lateral branch of 5; 9, posterior branch of 5; 11, left middle bronchus; 12, lateral branch of 11; 13, anterior branch of 11; *Dl*, dorsal branch of lower bronchus.

anterolateral segment on the right side, except that it is somewhat larger and is fused below with the segments supplied by the left middle bronchus. Sometimes a fissure exists in this situation corresponding to the lesser fissure

in the right lung, and Churchill and Belsey (1939) have pointed out that there is normally an obvious notch on the anterior border of the left upper lobe at the junction of the upper and middle areas (Fig. 8 and Plate IX).

(*b*) Apicoposterior (axillary-apical): This is a short trunk directed vertically upwards, and dividing into *apical* and *posterolateral* branches. These have exactly the same divisions, direction and distribution as the corresponding branches in the right lung; but the left posterolateral branch is usually smaller than the right. The left apicoposterior segment corresponds to the combined apical and posterolateral segments of the right upper lobe and has similar relations (Fig. 8).

2. **The left middle bronchus** (left middle lobe bronchus, lingual bronchus, pectoral bronchus): This bronchus is directed forwards, downwards and outwards and divides into two branches, *anterior* and *lateral*; its distribution

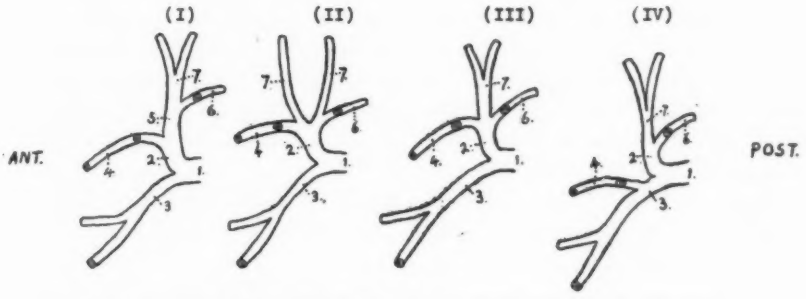

FIG. 11.—THE HYPARTERIAL BRONCHUS: VARIATIONS IN BRANCHING.

1, hyparterial bronchus; 2, ascending bronchus; 3, left middle bronchus; 4, anterolateral division; 5, apicoposterior division; 6, posterolateral branch; 7, apical branch. All viewed from the lateral aspect.

is similar to that of the right middle bronchus. The segment which it supplies is often called the " lingula " or " lingual process of the left upper lobe," and its importance in thoracic surgery has been discussed by Churchill and Belsey (1939).

Variations which have been observed in the mode of branching of the hyparterial bronchus are shown diagrammatically in Fig. 11, and their frequency is given in Table II. They are less important than those of the eparterial bronchus because the bronchoscopist is rarely able to see the orifices of the divisions of the ascending bronchus.

All the branches of the hyparterial bronchus can be identified in a good bronchogram, provided that both postero-anterior and lateral films are studied; a view taken in the right anterior oblique position usually shows the hyparterial bronchus more clearly than a straight left lateral film (Plate V).

(C) *The Lower Lobes.*—**The lower bronchus** (lower lobe bronchus) is similar in form, distribution and mode of branching in the two lungs, except that the cardiac branch is absent on the left side. The *right lower bronchus* is the direct continuation of the descending bronchus distal to the origin of the right middle bronchus. The *left lower bronchus* is the continuation of the left main bronchus distal to the origin of the hyparterial bronchus.

The lower bronchus is directed downwards, outwards and backwards; it is about 2 cm. in length and ends by dividing to form the middle basic and posterior basic bronchi (Plates VI, VII and VIII); the latter represents the terminal part of the primitive bronchial stem. Lucien and Weber (1936) have shown that the stem bronchus (lower bronchus and posterior basic branch) is not straight, but curves round backwards and medially to end in the lower paravertebral region; this imparts a lateral direction to the lower ventral branches (anterior and middle basic). The lower bronchus gives rise to the following branches, from above downwards:

1. Dorsal (first dorsal, posterior horizontal, apical bronchus of lower lobe, dorsal lobe bronchus): This arises from the posterior wall of the lower bronchus at its origin. It is about 0·5 cm. in length and at first is directed backwards and downwards, but, almost immediately, bends upwards into the horizontal position and ends by dividing into a varying number of branches, usually four. These have a backward direction, and they radiate out from the dorsal trunk to supply the apex of the lower lobe. This segment is related behind to the paravertebral gutter and laterally to the chest wall, its anterior angle extending almost as far forwards as the mid-axillary line; it is bounded above and in front by the greater fissure, and its medial surface is in contact with the vertebral column as far down as the ninth or tenth thoracic vertebra (Fig. 8).

Nelson (1932) was the first to point out that this dorsal segment may be regarded almost as an independent lobe. It is often separated from the rest of the lower lobe by a partial or complete fissure (Plate IX), its bronchus is almost as large as the middle bronchus and represents the first dorsal branch of the primitive bronchial stem; and it has an independent blood supply derived from the inferior division of the pulmonary artery and the inferior pulmonary vein. This view has also been held by Levitin and Brunn (1936), and Churchill and Belsey (1939) pointed out that, even when a fissure is not present, surgical separation of the dorsal segment from the rest of the lower lobe is usually easy.

As would be expected from embryological considerations, there is a regular series of dorsal offshoots below the dorsal bronchus. These vary in number up to three, and they arise from the lower bronchus and its

posterior basic branch. Neil, Gilmour and Gwynne (1937) and Twining (1938) have described a separate broncho-pulmonary segment supplied by the first of these twigs which was called by Aeby (1882) the " second dorsal bronchus," and by Ewart (1889) the " lesser posterior horizontal bronchus." This segment is said to lie between the dorsal and posterior basic segments (Fig. 6); but while the bronchoscopist should remember the existence of these lesser dorsal branches, they are not sufficiently constant in their arrangement to warrant this addition to the already numerous broncho-pulmonary segments.

2. Cardiac (retro-cardiac, para-cardiac, infra-cardiac, mesial): This is a well-marked branch which exists only in the right lung; it is directed downwards in the form of a curve, the convexity of which is directed forwards and medially, and it divides into branches which supply a small segment of the medial aspect of the right lower lobe below the hilum. This segment is related medially to the lateral surface of the pericardium, and sometimes exists as a supernumerary lobe which has been called the " cardiac " or " lower azygos " lobe (Stibbe, 1919). Ewart (1889) and Lucien and Weber (1936) have stated that this bronchus is represented in the left lung by a branch of the left anterior basic bronchus.

3. Anterior basic (lower anterolateral): This is a large branch arising from the antero-lateral aspect of the lower bronchus about 1 cm. from its origin; it is directed downwards, forwards and laterally, and its branches supply the anterior part of the lower lobe. This segment is related laterally to the chest wall as far back as the mid-axillary line, medially to the pericardium, below to the diaphragm, and its antero-superior surface is bounded by the greater fissure.

4. Middle basic (lower posterolateral, axillary basic): The middle basic bronchus is one of the branches of the terminal bifurcation of the lower bronchus, and is directed downwards and laterally. The segment which it supplies lies between those of the anterior and posterior basic bronchi; it is related laterally to the chest wall, below to the diaphragm, and medially on the left to the mediastinum, and on the right to the cardiac segment.

5. Posterior basic (lower paravertebral): This is the other branch of the terminal bifurcation of the lower bronchus, and it continues the curve of the stem bronchus downwards, backwards and medially to supply the posterior and lowest portion of the lower lobe. This segment is related laterally to the chest wall, extending forward to the posterior axillary line, behind to the paravertebral gutter, medially to the vertebral column, and below to the diaphragm.

All the branches of the lower bronchus can be demonstrated with the aid of postero-anterior and lateral bronchograms (Plates VI, VII and

VIII). The cardiac branch is often overlooked, but it is readily recognised by its characteristic shape and is particularly well seen in the right anterior oblique view.

Summary

From a consideration of the embryology and comparative anatomy of the bronchial tree, it is shown that the fundamental design in each lung consists of a stem bronchus having a series of dorsal and ventral branches. The upper part of the lung has a separate stem with similar branches; on the right this stem, the eparterial bronchus, has an independent origin, while on the left it develops from a special ascending branch of the first ventral hyparterial bronchus.

After reviewing accounts of the anatomy of the bronchi in man, a description of the human bronchial tree is given, based upon a study of 200 bronchograms as well as dissections, inflation preparations and celloidin casts. Each important branch of the bronchial tree is described, together with its bronchographic appearance and the pulmonary segment which it supplies.

In the nomenclature of the bronchial tree, it is suggested that the word "lobe" should be omitted when naming individual bronchi since the lobar distribution differs on the two sides. Thus the bronchi to the right and left upper lobes are distinguished as eparterial and hyparterial respectively, while the bronchus to the right middle lobe and its equivalent on the left side are called the right and left middle bronchi; the bronchus to the lower lobe is termed simply the lower bronchus. In over 80 per cent. of subjects the eparterial bronchus has three branches—apical, anterolateral and posterolateral; the lateral or axillary branch with its separate segment, formerly described as common, is in fact a rare variation. The importance of this concerns the localisation and bronchial drainage of lesions in the right upper lobe; for the axillary catchment area is actually drained by branches of the anterolateral and posterolateral divisions, and on looking into the eparterial bronchus, no branch going exclusively to the axilla is usually visible. Other modes of branching of the eparterial bronchus, and those affecting the hyparterial bronchus on the left side, are also described.

The arrangement of the bronchi in the rest of the lungs was found to be substantially that described by most previous authors.

APPENDIX

Methods of Investigating the Bronchial Tree

1. Celloidin Corrosion.—The method to be described is a modification of that devised by Hinman, Morrison and Lee-Brown (1923) for demonstrating the vascular system. In order to prevent the main bronchial

divisions from being obscured by celloidin in the alveoli, it is necessary to use a very thick injection mass and little pressure. The injection mass consists of: acetone, 100 c.c.; X-ray film, 20 grammes; camphor, 15 grammes.

As soon as possible after death the trachea is opened in the neck and the bronchi are washed with water until all mucus has been removed; a bronchoscope is useful during this procedure. A large glass cannula is then tied into the trachea and connected by wide-bore rubber tubing to a large funnel held about 1 foot above the neck. The injection mass is then poured very slowly down the side of the funnel, thus expelling as much air as possible from the trachea and bronchi. Eventually the funnel will fill up and should be left filled for at least twenty-four hours or longer so that the cast can set, more of the mass being added as necessary. At the end of this time the tube is clipped off, and the anterior chest wall removed by dividing the ribs in the mid-axillary line on both sides. The thoracic viscera are then lifted out very gently, great care being taken not to disturb the position of the lungs in any way. They are attached to a wooden bar by three separate ligatures passing from the bar, one around the trachea and two others through the apices of the lungs. The viscera are then suspended in a large vessel, the bar resting across the vessel's mouth. Commercial hydrochloric acid is poured in until the bases of the lungs barely float; more acid must not be added at this stage lest the lungs float outwards and the cast be distorted. On the following day, and on each subsequent day until completion, the viscera are lifted out of the acid and the macerated parts are washed off with a fine jet of water. The organs are then replaced and more acid is added as before until the lungs barely float. The whole process takes about ten days to complete. Using this technique, the celloidin does not reach beyond the peripheral bronchioles of about 1 mm. diameter, so that the resulting cast clearly demonstrates the principal branches.

2. Inflation.—This is the simplest method of demonstrating the broncho-pulmonary segments. After removal of the intact lung, the stem bronchus is opened and a short piece of rubber catheter is plugged into the chosen branch. Air is then pumped into the catheter with a Higginson's syringe; the corresponding pulmonary segment inflates and stands out as a raised, pink area against the dark collapsed lung around.

3. Injection of Dyes.—The pulmonary segments may be distended with a preservative solution which has been coloured with water-soluble dye, and in this their positions may be outlined on the surface of the lung.

4. Bronchography.—A good bronchogram in the living subject will show the positions of all the important bronchi, provided that both postero-anterior and lateral films are taken, and considered together. Only one

lung must be filled, otherwise the lateral film will be confused owing to the superimposition of the bronchi of the two sides. The production of a well-filled bronchogram depends upon two factors—first, the oil must be introduced with certainty into the trachea, and second, the patient must be placed in a series of positions designed to cause the oil to gravitate into every part of the bronchial tree. This technique has been described by Erwin (1936), and by Beaumont and Dodds (1941); very briefly, the procedure is as follows: The skin over the crico-thyroid membrane is anæsthetised, and 0·5 c.c. of a 2 per cent. "Decicaine" solution is injected into the trachea with a stout needle, to anæsthetise the larynx. A wide bore needle attached to a syringe containing 15 c.c. of the oil is then pushed through the membrane and, with the patient in a semi-recumbent posture, inclined towards the side to be filled, 5 c.c. of oil are injected to outline the posterior part of the lower lobe. The patient is then sat up and leant forward as far as possible, still keeping inclined towards the side which is being filled, and 5 c.c. of oil are introduced to outline the anterior part of the lower lobe and, on the right side, the middle lobe. Finally, the patient lies down on the side which is being filled, the remaining 5 c.c. of oil are injected, and should run into the eparterial or hyparterial bronchus. The needle is then withdrawn, and the patient is turned first on to his face, then on to his back, and finally on to his side, and the foot of the table is raised; these movements cause the oil to gravitate into the anterior, posterior and apical regions of the upper lobe. When taking oblique bronchograms the chest should be at an angle of about 40 degrees to the film; the left bronchial tree is best seen in the right anterior oblique view and *vice versa* (Plate V).

I wish to record my gratitude to Dr. R. L. Rawlinson, Dr M. MacHugh and Mr. J. W. Spence, and to their staffs in the Radiological and Pathological Departments and the Dispensary of the Brompton Hospital, for the willing and valuable assistance which they have given me in this investigation.

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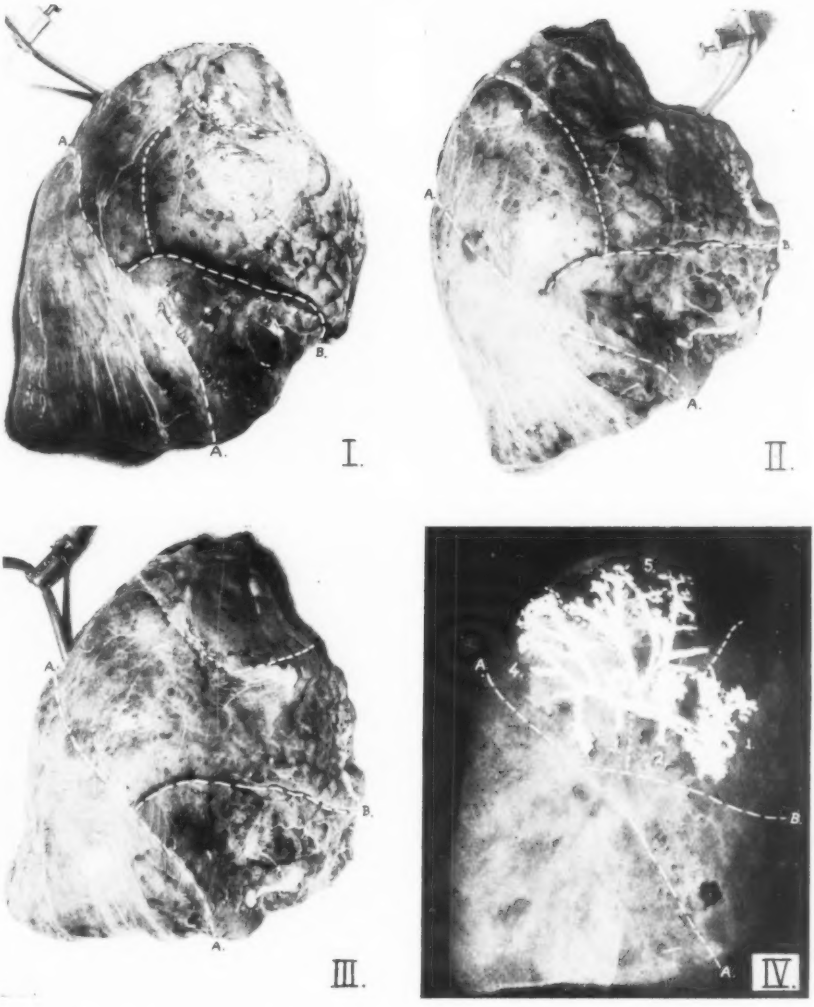
PLATE I



INFLATION OF THE RIGHT UPPER LOBE SEGMENTS IN THE CADAVER.

I. ANTEROLATERAL SEGMENT INFLATED.

II. POSTEROLATERAL SEGMENT INFLATED.

III. APICAL SEGMENT INFLATED.

IV. BRONCHOGRAM OF THE EPARTERIAL BRONCHUS AND ITS BRANCHES IN THE CADAVER.

A, greater fissure; B, lesser fissure; 1, anterior part of anterolateral branch; 2, lateral part of anterolateral branch; 3, lateral part of posterolateral branch; 4, posterior part of posterolateral branch; 5, apical branches.

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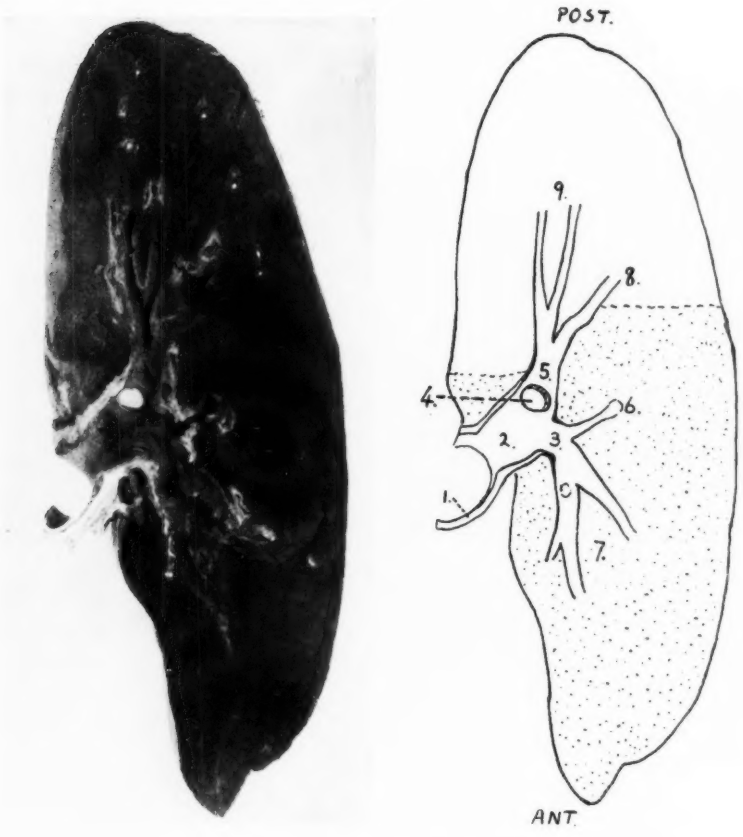
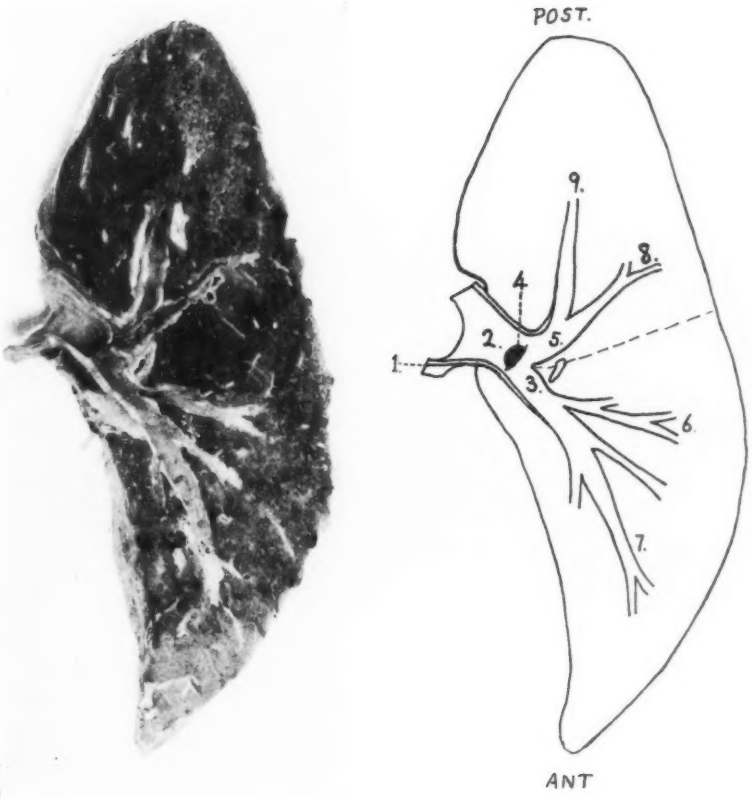
PLATE II



THE EPARTERIAL BRONCHUS (VARIATION V).

Horizontal section through right upper lobe at the level of the eparterial bronchus; the branch bronchi were injected with different dyes. The section is viewed from below. 1, main bronchus; 2, eparterial bronchus; 3, anterolateral branch; 4, apical branch; 5, posterolateral branch; 6, lateral division of 3; 7, anterior division of 3; 8, lateral division of 5; 9, posterior division of 5.

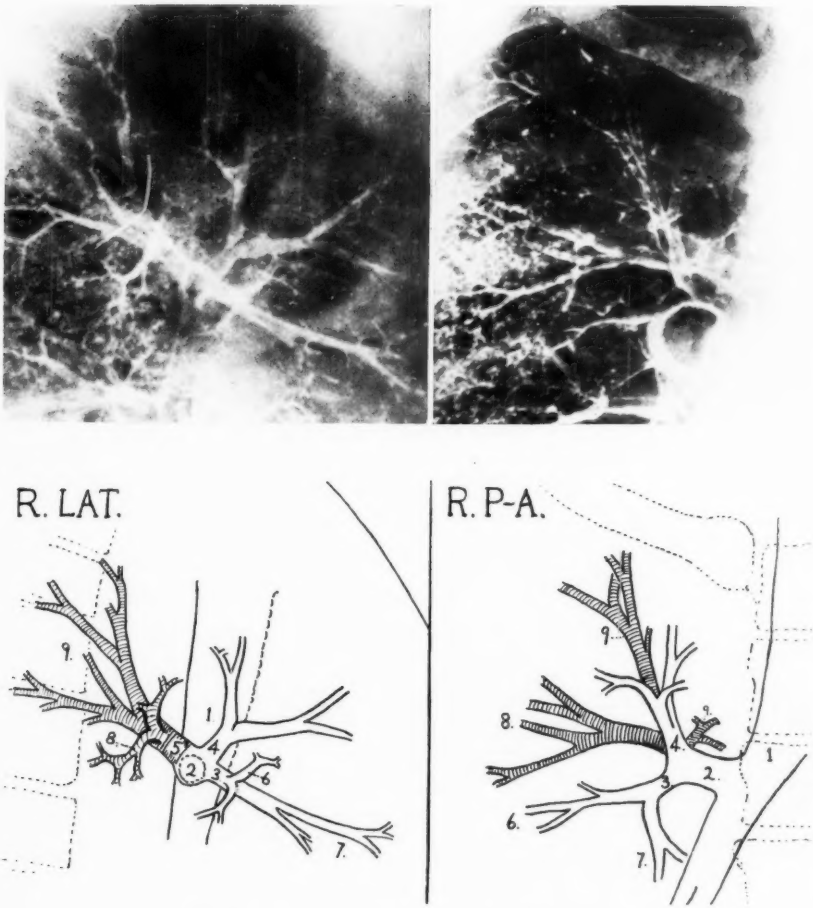
PLATE III



THE NORMAL EPARTERIAL BRONCHUS.

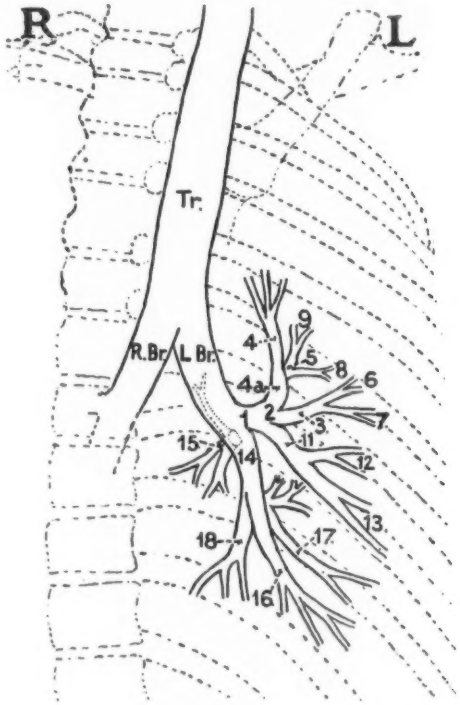
Horizontal section through right upper lobe at the level of the eparterial bronchus. The section is viewed from below. 1, main bronchus; 2, eparterial bronchus; 3, anterolateral branch; 4, apical branch; 5, posterolateral branch; 6, lateral division of 3; 7, anterior division of 3; 8, lateral division of 5; 9, posterior division of 5.

PLATE IV



BRONCHOGRAM OF THE EPARTERIAL BRONCHUS.

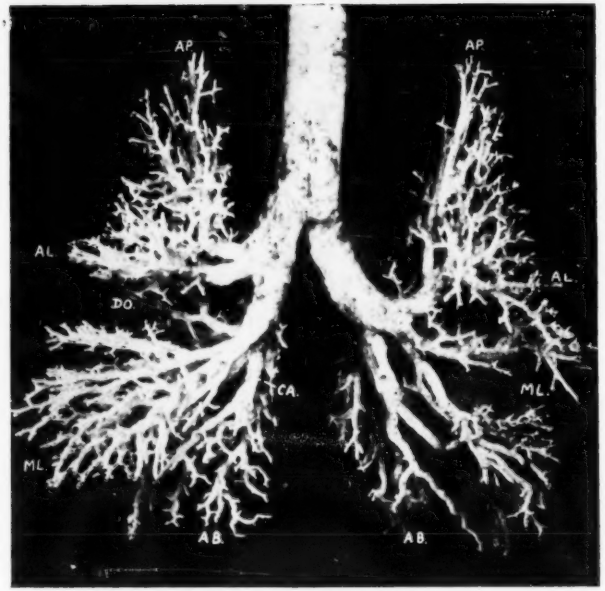
1, main bronchus; 2, eparterial bronchus; 3, anterolateral branch; 4, apical branch; 5, posterolateral branch; 6, lateral division of 3; 7, anterior division of 3; 8, lateral division of 5; 9, posterior division of 5.

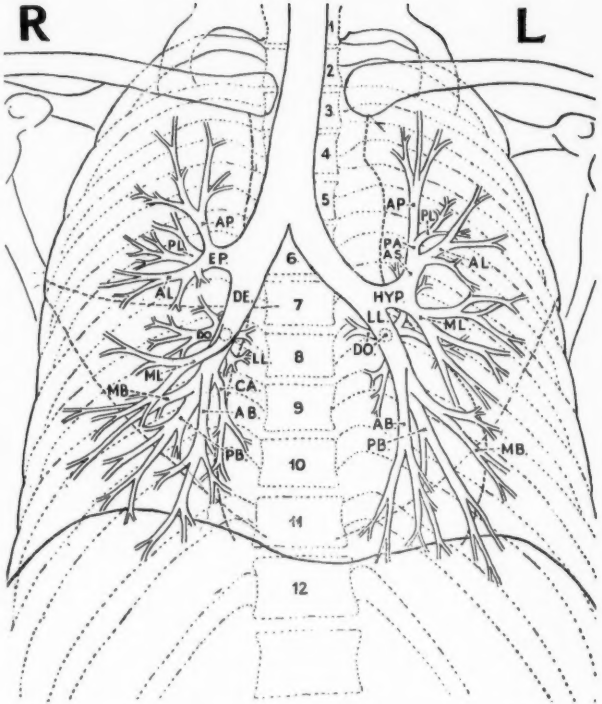


LEFT BRONCHOGRAM IN THE RIGHT ANTERIOR OBLIQUE POSITION.

1, hyparterial bronchus; 2, ascending bronchus; 3, anterolateral division; 4*a*, apicoposterior division; 4, apical branch; 5, posterolateral branch; 6, lateral branch of 3; 7, anterior branch of 3; 8, lateral branch of 5; 9, posterior branch of 5; 11, middle bronchus; 12, lateral branch of 11; 13, anterior branch of 11; 14, lower bronchus; 15, dorsal branch; 16, anterior basic branch; 17, middle basic branch; 18, posterior basic branch.

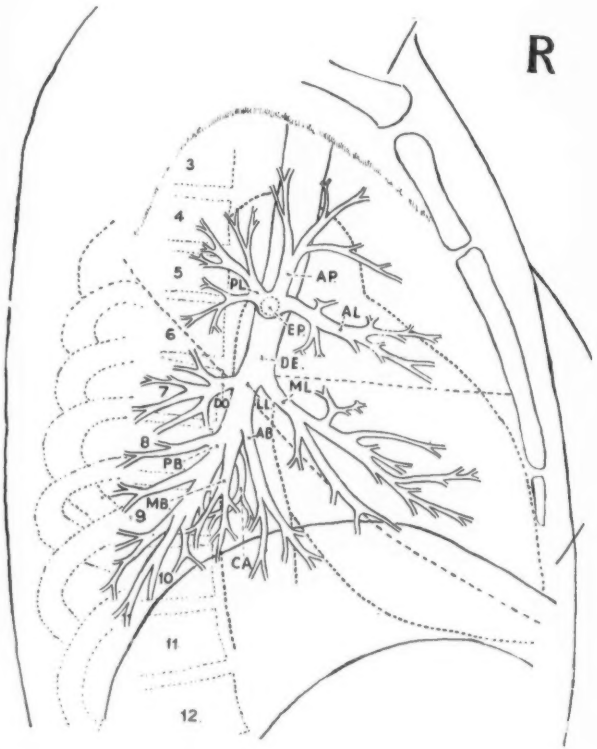
PLATE VI





THE NORMAL BRONCHIAL TREE, DEMONSTRATED BY BRONCHOGRAPHIC TRACINGS AND A CELLOIDIN CAST: ANTERIOR VIEW.

EP, eparterial bronchus; AL, anterolateral branch; AP, apical branch; PL, posterolateral branch; HYP, hyparterial bronchus; AS, ascending bronchus; PA, apicoposterior branch; DE, descending bronchus; ML, middle bronchus; LL, lower bronchus; DO, dorsal branch; CA, cardiac branch; AB, anterior basic branch; MB, middle basic branch; PB, posterior basic branch.



THE NORMAL BRONCHIAL TREE, DEMONSTRATED BY BRONCHOGRAPHIC TRACINGS AND A CELLOIDIN CAST: RIGHT LATERAL VIEW.

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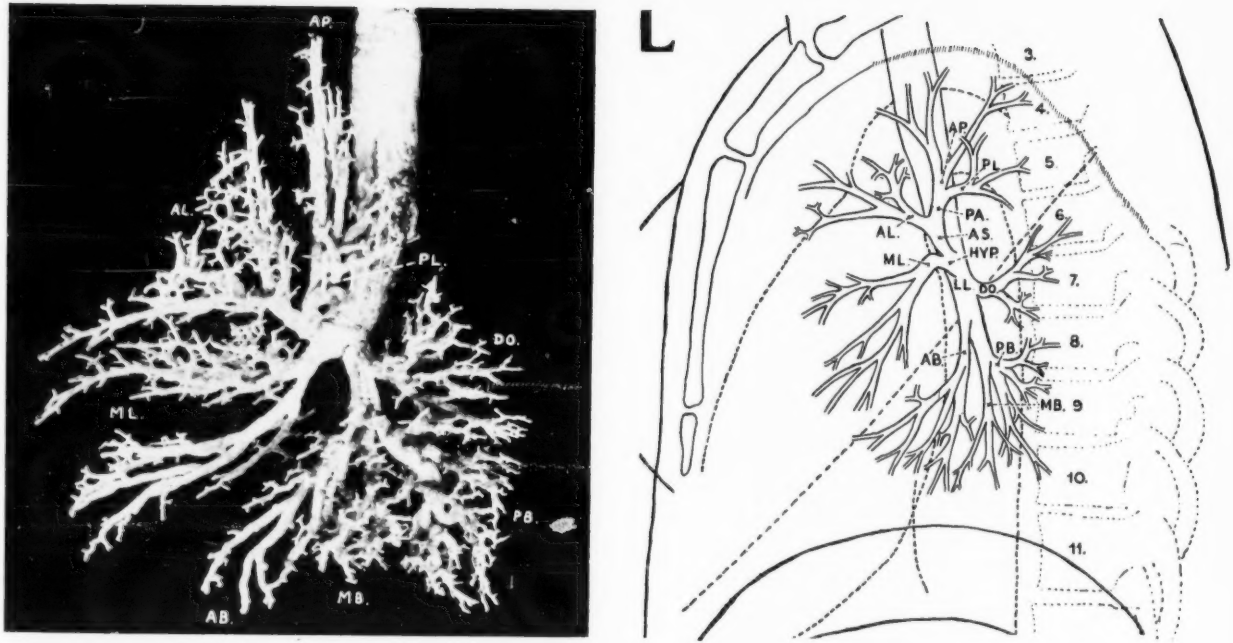
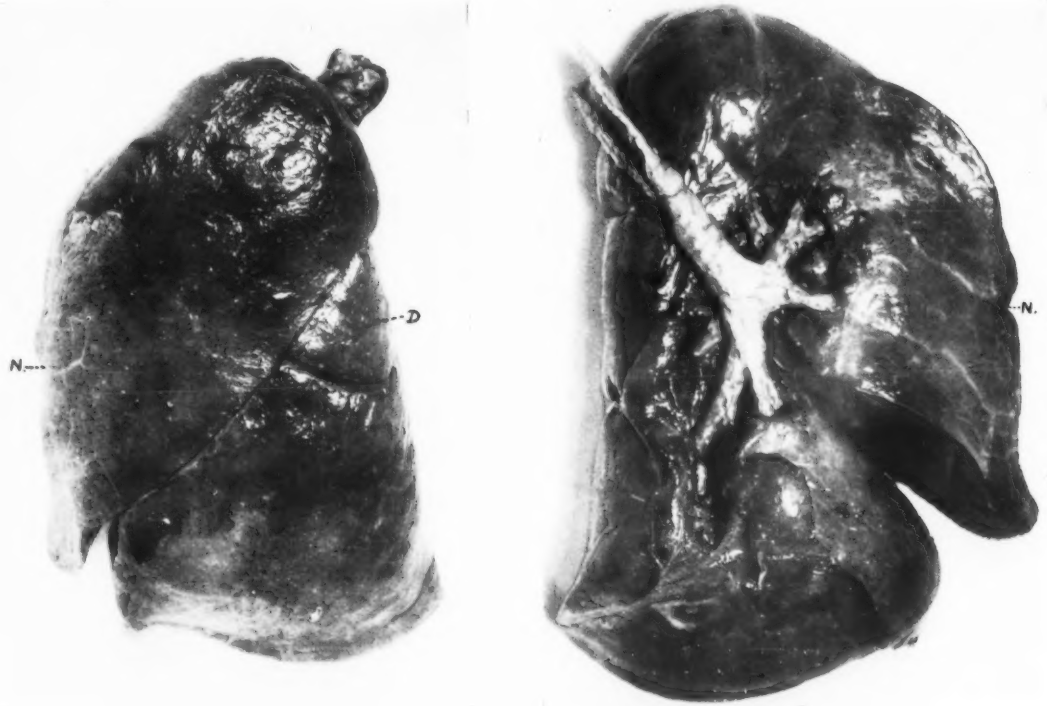
PLATE VIII



THE NORMAL BRONCHIAL TREE, DEMONSTRATED BY BRONCHOGRAPHIC TRACINGS AND A CELLOIDIN CAST: LEFT LATERAL VIEW.

PLATE IX



LEFT LUNG SHOWING DORSAL LOBE.

D, dorsal segment separated from remainder of lower lobe by a deep fissure on the lateral surface. N, notch on anterior border marking the junction of the upper and middle portions of the left upper lobe.

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MEETINGS OF SOCIETIES

JOINT TUBERCULOSIS COUNCIL

A MEETING of the Joint Tuberculosis Council was held at the London School of Hygiene and Tropical Medicine, London, on Saturday, November 22, 1941. Dr. D. A. Powell (Wales) was in the Chair and twenty Members of the Council were present. A welcome to the Council was given to Dr. J. Ferguson (Surrey), representing the Society of Medical Officers of Health, and to Dr. G. B. Dixon (Birmingham), the new representative from the National Association for the Prevention of Tuberculosis. The following were nominated as officers for 1942:

Chairman : Dr. D. A. Powell (Wales).
Vice-Chairmen : Dr. James Watt (Godalming) and Dr. Edward Ward (Devon).
Hon. Treasurer : Dr. G. Jessel (Lancashire).
Hon. Auditor : Dr. D. P. Sutherland (Manchester).
Hon. Secretary : Dr. J. B. McDougall (Preston Hall, Kent).

Post-Graduate Courses.—Dr. F. R. G. Heaf (London) gave an account of the recent course of post-graduate study held at Harefield Sanatorium with permission of the Middlesex County Council. It is probable that a further course will be held in the north of England in 1942.

Care and Rehabilitation Report.—It was reported by the Conveners of the Rehabilitation Committee (Dr. J. B. McDougall, Kent, and Dr. F. R. G. Heaf, London) that the Committee had agreed that for purposes of publication the Report should be divided into two parts, the first dealing with Rehabilitation and the second with Care Committees, and the Council

agreed that the publication of Part 1 be proceeded with at the earliest possible moment. It is hoped that Part 2 will be published early in the new year. Arising out of the discussion of the Rehabilitation Report, the question was asked whether the recent circular from the Ministry of Labour outlining "An Interim Scheme for the Training and Resettlement of Disabled Persons" was in keeping with the general views of the Rehabilitation Committee. The Hon. Secretary pointed out that the Ministry of Labour scheme could not apply to persons suffering from tuberculosis unless there was the closest co-operation between tuberculosis physicians and the Ministry of Labour visitor to the hospitals concerned. The possible repercussions from arranging for the entrance into the Labour Ministry Training Centres of relatively advanced patients with open tuberculous disease might be grave. There was apparently some misunderstanding on this subject by representatives of the Ministry of Labour in districts. The Council agreed that the Ministry of Health, Labour and Pensions should have this matter brought to their notice.

Finance.—The Hon. Secretary reported on the steps he had taken to secure additional financial assistance for the Council in its work of circulating reports and reprints of reports, and hoped to be able to report even more favourably at a future meeting. Meanwhile, he announced that the American Tuberculosis Association had agreed in advance to purchase reprints of the Care and Rehabilitation Committee's Report.

Councils and Committees on Tuberculosis.—A list of seven different Committees or Councils at present undertaking research and investigations into problems affecting tuberculosis in this country was given, and a discussion took place on the multiplicity of Committees on one and the same subject. It was generally agreed that this represented a waste of effort and ought to be avoided by the closer co-operation between existing organisations, and the Secretary was instructed to draw the attention of the Ministry of Health to the desirability of centralising investigations around existing organisations dealing with this subject.

Thoracic Surgery Report.—Mr. J. E. H. Roberts (London), in a private communication, reported that the Society of Thoracic Surgeons had been invited to prepare a memorandum on Thoracic Surgery by the Ministry of Health. He suggested further that this report might at a later date be considered by the Joint Tuberculosis Council for criticism and suggestions prior to submitting it to the Ministry. The Council accepted Mr. Roberts' suggestion.

It was decided to hold the next meeting at 2 p.m. on the afternoon of Friday, February 20, 1942, in London.

REVIEWS OF BOOKS

A Textbook of the Practice of Medicine. Sixth Edition. Edited by FREDERICK W. PRICE, M.D., C.M., F.R.C.P., F.R.S.(Edin.). London: Humphrey Milford, Oxford University Press. Pp. 2032. Price 38s.

This, the first war-time edition, of a well-known textbook, appears after a revision which all will realise must have been difficult. But the revision has been done well, and the book fully maintains the standard set by previous editions. New articles have been added dealing with leptospirosis, epidemic myalgia, pink disease, injuries from X-rays, virilism, idiopathic steatorrhœa, adenoma of bronchus, congenital cystic disease of lung, pneumonitis, sarcoidosis, and hypertensive encephalopathy, among others. Many other sections have undergone considerable revision by the addition of new matter and correction of statements now thought to be erroneous. The result is a book which fairly represents the current teachings of English medicine in most important matters, and one which is replete with detailed information.

The Story of Clinical Pulmonary Tuberculosis. By LAWRASON BROWN, M.D., Late Director of Trudeau Sanatorium; Lecturer in Trudeau School of Tuberculosis. London: Baillière, Tindall and Cox, 1941. Price 15s.

In this volume the author has collected a mass of fascinating facts about the history of pulmonary tuberculosis and has presented them in the form of a most readable story. Here one may find such things as the history of the stethoscope, the evolution of the sanatorium or the development of surgical treatment in pulmonary tubercle. The author has not neglected the historical background which accompanied each scene in the medical drama, and he includes short biographical sketches of the leading personalities. The fact that Corvisart in 1785 wrote his M.D. thesis on "The Pleasures of the Study of Medicine and the Disagreeableness of its Practice" is only one of the many entertaining things which are recounted in this book. The whole work is well documented, and there is a useful bibliography. Anyone who is concerned with pulmonary tuberculosis will find this book valuable both for reference and for recreation.

Architectural Principles in Arthrodesis. By H. A. BRITTAIN. Edinburgh: E. and S. Livingstone. Price 21s.

Mr. Brittain discusses the indications for performing an arthrodesis and stresses the fact that the operation is apt to fall short of expectation. He believes that the causes of failure of fusion can be diminished by attention to the following principles:

1. Adequate apposition.
2. Adequate immobilisation.
3. Operating only when the limit of bone destruction has been reached.
4. Avoiding operations based on faultily conceived mechanical principles.

It is with the last of these that the monograph is particularly concerned, and the author elaborates the point by references to certain well-accepted architectural principles.

1. The graft should be placed with its long axis in compression rather than in tension.
2. The breadth of the graft should be placed in the position of maximum stress.
3. A joint should be locked by two grafts crossing each other in the shape of the letter X.
4. There should be adequate protection of the graft.

These theoretical points are followed by a detailed description of the author's technique for performing an arthrodesis of each of the major joints of the body. The most important new suggestions are the operation of ischiofemoral arthrodesis in the case of the hip, and extra-articular posterior scapulohumeral grafting in the case of the shoulder joint. In the foreword Mr. Harry Platt describes these operations as notable contributions.

This monograph is short and takes about an hour to read; it costs 21s. It contains a large number of diagrams so clear and tidy that the operations look easy, and it is obvious that no trouble has been spared in the production of the material. Indeed, in a book of 132 pages, it is surprising that the publishers have been able to include 25 which are quite blank.

Mr. Brittain is to be congratulated on the novel and ingenious procedures which he describes, but this reviewer doubts whether the lavish scale of production may not limit the number of surgeons who will find access to this work.

CORRESPONDENCE

ADVICE ON THE MANAGEMENT OF A NEW *SPECIES*

" There's a grain or two of wisdom in the chaff."

SIR,

The mammals began to dominate the land, the sea and the air of this planet in the Mesozoic Era. At first they were small and unobtrusive creatures who pitted wits and speed against the heavy armour and slow cerebration of the giant dinosaurs. Later they multiplied and thrived exceedingly and the reptiles became extinct.

The student of zoology is in doubt as to the cause of the decline of so powerful a species, and facts, theories and oddities have been adduced to explain the circumstances. Amongst these is the cunning suggestion that the mammals exterminated the reptiles by the simple expedient of eating their eggs.

It is trite to remark that history repeats itself, but a new species has appeared amongst those who, for generations, have held a monopoly in the treatment of pulmonary tuberculosis and it threatens to " eat their eggs." The sanatorium doctor today is exposed to the machinations of the species " Thoracic Surgeon," and as the danger spreads the need for organised resistance increases, lest the old should perish at the hands of the new.

From the beginning of time, when medicine was interwoven with other nebulous sciences, it has been customary for physicians to regard the chest as their sphere of special influence. No surgeon of repute has challenged this conception. Generations of doctors have tapped on the outside of the ribs, listened to the heart and lungs from afar, and guessed at the hidden changes within. The exactness of these methods of diagnosis has not been disputed, and the secrets of their application have been guarded from the general surgeon. It is reassuring to observe the kindly smile of a physician as he watches a surgeon trying to use a stethoscope.

It is not surprising that the management of pulmonary tuberculosis should have passed under the wing of such reliable men of science as Thoracic Physicians. With wise judgment and long vision they have organised and practised successful methods of treatment which have not been modified for hundreds of years. The profession, the patient and the tubercle bacillus have all been satisfied.

Into this realm of peace the species " Thoracic Surgeon " has abruptly thrust himself. He poses as the herald of new methods and brands the Sanatorium Expert as a type showing racial senescence. He affirms that, just as individuals grow old and suffer retardation of vital activities, the species " Medical Superintendent " shows unmistakable signs of lowered vitality and diminished mental activity. " In every new species the rate of metabolism is high and manifests itself in active life, predacious habits, small to moderate build, and lack of heavy excrescences. An old species is characterised by sluggish behaviour, specialised anatomy and ideas, large build, and protected by impenetrable body armour." So speaks the tyro; his arguments are transparently false.

It is customary for zoologists to examine the descent of a new species, and, in searching for its origin, to employ three sets of criteria: fossils, ontogenies and homologies. In the case of the species " Thoracic Surgeon " we are faced with a lack of material in all these fields of research. There are no fossil specimens available for study, and the evidence of embryology is also meagre, although Stephen Paget wrote, in the days before thoracic surgery had been born: " Fifty years ago it had risen above the horizon; it is now nearly at its zenith "; and in the same year (1895) Reclus wisely said: " Resection of a part of the lung is not even worth discussing." Homologies form the subject-matter of comparative anatomy, and the accepted theory is that Thoracic Surgeons are derived from unsuccessful physicians.

The earliest examples of the species appeared in Egyptian times, and murals show them to have been akin to ordinary physicians; they did, however, " cut for the empyema." The recent and more dangerous outcrop sprang forth in the nineteenth century, and many specimens were observed in Central Europe and North America. Some of these made

startling contributions and followed so many blind paths that their names are remembered today. Carson, Murphy, Sauerbruch and Brauer will serve as examples.

Thoracic Surgeons are still a rare species, but can no longer be regarded as harmless. They are possessed of certain peculiarities which are liable to disarm the unwary sanatorium doctor. These peculiarities will be briefly described. The type is fast-moving, slick, and most self-assured; it is apt to take over your castle before the hearth has even been crossed. It exhibits a tendency to experiment with new and unproven methods, and unbounded optimism is a salient characteristic. Time-honoured remedies such as bed-rest and the routine charting of the pulse are brushed aside as useless, and operation is recommended as a panacea.

How is this dangerous infiltration to be met, and with what methods can it be nullified? The remedy is simple and within the grasp of all; it can be summed up in the words " Passive Resistance."

When a Thoracic Surgeon sweeps into your institution receive him with cold politeness, and assiduously avoid conversation on matters concerned with pulmonary tuberculosis; direct discussion towards topics of gentlemanly interest (about which he knows little), such as fishing for pike in the local pond, or the finer points in the playing of bowls. In this way superiority of intellect may be established from the first, and, although a Thoracic Surgeon can never be made to feel small, his mental stature can be reduced. If your outer perimeter of defence works is pierced and he gains a foothold in your sanatorium, the situation can still be retrieved, although extirpation of the species is long and tedious. The best results can be had by harping on the failures of " surgical interference," and by continually quoting the opinions of obscure writers who maintain that the successes of surgery are few and far between. A more subtle but effective method is to suggest that you have a measure of sympathy with the new cult, and at the same time to tell your patients that thoracoplasty is a cumbersome form of suicide. When all else fails and the foundations of your stronghold are tottering there is nothing left but to play your last card, and to wear the intruder out by recommending innumerable cases for avulsion of the phrenic nerve. It is a golden rule to submit only " graveyard cases " for major thoracic operations. No Thoracic Surgeon can stand up to this indefinitely.

If the reader has followed the argument to this point, it is reasonable to assume that time hangs heavily on his hands.

I am, Sir,
Yours faithfully,
A MEDICAL PRACTITIONER.

THE EDITOR,
THE BRITISH JOURNAL OF TUBERCULOSIS,
W.C. 2.

[Replies are invited from those who have suffered.—ED.]

NOTICE

THE following letter was sent from the Ministry of Health on November 5 last to all Welfare Authorities in England:

SIR,

Distribution of Fruit Juices and Cod-Liver Oil

1. I am directed by the Minister of Health to state that he has been in consultation with the Minister of Food in regard to the issue of certain preparations for young children. In order to ensure that the development of these children shall not, through difficulties of war-time feeding, suffer because of shortage in their daily intake of vitamins, the Ministry of Food is making available fruit juices and cod-liver oil sufficient to meet the needs of all children under two for vitamin C and vitamins A and D. As children over two years old can obtain all the vitamins they need from fruit and vegetables, the distribution of the fruit juices will be confined to children under two. It is hoped shortly to extend the issue of cod-liver oil to all who hold the child's ration book.

2. For practical reasons, it has been decided to arrange for the distribution of these preparations through the local machinery of the Ministry of Food and the Welfare Authorities. The Minister recognises that all Local Authorities are already heavily burdened, but he is confident that they will welcome this opportunity of meeting deficiencies in the diet of young children, and he accordingly appeals to Welfare Authorities to do all they can in the ways outlined below to ensure that these preparations are given to every child who would benefit from them.

3. In order to keep the arrangements as simple as possible, the preparations are to be issued free of charge to all children within the age groups during the coming winter, though after the end of March, 1942, a charge may be made to parents who are not entitled to free milk under the National Milk Scheme.

4. The preparations to be distributed are (i) a 6 fluid ounce bottle of cod-liver oil (compound) containing six weeks' supply for one child; (ii) a 13½ fluid ounce bottle of black-currant syrup containing two weeks' supply for one child; (iii) an 8½ fluid ounce can of black-currant purée containing one week's supply for one child; (iv) a 6 fluid ounce bottle of concentrated orange juice containing about three weeks' supply for a child under six months and about two weeks' supply for a child between six months and two years. No child will have more than one of preparations (ii), (iii) and (iv) at one time, and the concentrated orange juice will probably not be issued before the middle of January, 1942.

5. The successful distribution of these preparations will depend first and foremost on co-operation between the Local Food Officers of the Ministry of Food and the Welfare Authorities and their Medical Officers and workers in the Maternity and Child Welfare Centres.

6. Broadly speaking, the function of the Local Food Office will be to do the organising work for the whole of the area for which it is responsible,

and that of the Welfare Authorities to do, so far as possible, the actual issue of the preparations to the parents. The Local Food Office will, for example, be responsible to the Ministry of Food for all stocks sent into its area, and it will be its task to see that the cases of bottles are distributed to the centres at which they will be available to parents, and that they are returned in due course when fresh supplies are required. All the paper work except the keeping of stock records in the place of issue and the marking of the ration book will be done by the Local Food Office.

7. The Welfare Authority, however, has a very big part to play in arranging as many points of issue as possible so as to prevent congestion. The Local Food Offices will be receiving a general statement of their part in the scheme, including an instruction to establish contact with the Infant Welfare Centres in their area, either direct or through the Medical Officer of Health—whichever method is the quicker and more convenient—and find out (*a*) how many points of issue can be arranged, (*b*) what storage space is available at each centre, (*c*) on what day of the week and at what times each centre could be open for the reception of the preparations, and (*d*) what number of parents could be catered for at each centre. This method of distribution is similar to that employed for National Dried Milk, but whereas there are only some 48,000 children taking National Dried Milk, it is expected that some 1,300,000 children will take advantage of this scheme. Hence, while the Local Food Offices may be able to undertake the issue of these preparations to parents to whom they already issue National Dried Milk, any attempt to cope with the bulk of the new beneficiaries at the Local Food Offices would cause intolerable congestion and delay. The Minister therefore appeals to Welfare Authorities to help in this scheme by every means in their power, by providing as many centres of issue as possible and by enlisting all available assistance, through voluntary workers as well as through their own officers, in finding outlets for the supplies provided.

8. Every Welfare Authority should arrange for the information suggested under (*a*) to (*d*) in paragraph 7 above to reach the Food Executive Officer by November 10. This could be done either directly by the Medical Officer of Health or by means of local arrangement between the Food Office and the Infant Welfare Centre.

9. It is desired to bring the scheme into operation on December 1; it is therefore hoped that the centres to be used for distribution may be decided at a very early date. The Local Food Office will then arrange suitable publicity by cinema slides and the local press so that parents may be informed, before the end of the month, of the facilities available.

I am, Sir,
Your obedient Servant,
B. L. PUXLEY.
(*Assistant Secretary.*)